

Moon Chronicle

CELLARUM

Part 1

Luna 1 to Lunar Orbiter 1



Luna 7

by



Luna 5

Surveyor 1



Phil Stooke



Ranger 7

MARE

Moon Chronicle

Part 1: Luna 1 to Lunar Orbiter 1

by

Phil Stooke

Introduction

When I was young, people first flew to the Moon. That's too good a line to use only once. It comes from my book *The International Atlas of Lunar Exploration* (published by Cambridge University Press, 2007) which was an attempt to tell the story of lunar exploration in atlas format, a book consisting half of maps and half of text, but very much concentrating on what could be mapped. Where on the Moon did the Apollo astronauts go, why did they go to those places, what did they do there? And what about robotic spacecraft, and all the missions planned or postulated along the way as people tried to decide how to explore a new world? That book answered those questions as well as I could manage before we had the bountiful data from the Lunar Reconnaissance Orbiter (LRO), but now it is very much out of date. Here I hope to tell the story again and to improve the telling in many ways. I correct errors (there were too many), I add details not included in the previous book, I use LRO data to improve almost every illustration, I add things not possible before LRO such as (in later volumes) accurate maps of the Apollo and Lunokhod traverses, and I bring it all up to date. Items are presented in the manner of encyclopedia articles with references attached, not all collected in one big bibliography. The result is a very different and greatly improved work, a chronology, an encyclopedia and an atlas combined.

I don't write about space technology, non-lunar space flight, space politics, astronomy, lunar geology or the many people involved in this work, with a few exceptions where it makes sense to do so. Readers should check the introduction to the previous atlas for an explanation of conflicting coordinates, but briefly coordinate formats are as given in the sources, so decimal degrees and minutes and seconds are mixed, and no attempt is made here to update locations to match modern coordinate systems. I use longitudes measured east and west from the central meridian, following Apollo usage. I don't show the north direction on maps or images as a labeled grid or a context map will indicate this, and all non-polar figures are oriented with north at or near the top unless specifically noted. Basic mission descriptions are chiefly from the NASA Space Science Data Coordinated Archive (NSSDCA) (which was at <https://nssdc.gsfc.nasa.gov/planetary/lunar/lunartimeline.html> in August 2020). Material on Soviet plans includes details from Mark Wade's Encyclopedia Astronautica (<http://www.astronautix.com>).

The many people who helped me during the earlier work are acknowledged in the original Atlas and I continue to be grateful to them, but some additional acknowledgements are necessary. Ken McTaggart and Jim Scotti kindly pointed out some errors in the first edition. Irina Karachevtseva of MIIGAiK provided additional information on the Lunokhod missions. The following all helped when I asked for assistance: Doug Ellison, Brian Harvey, Graham Donald, Norman Crabill, Ian Regan, Paul White, David Portree and Lucy Walsh at USGS Flagstaff, Brian McInall and Catherine Neish. I also acknowledge help from the library staff at the Lunar and Planetary Institute and the Lunar and Planetary Laboratory of the University of Arizona, and the continued support and encouragement of the Faculty and students of the Centre for Planetary Science and Exploration (CPSX), more recently the Institute of Earth and Space Exploration at the University of Western Ontario. If you should be on this list and are not, I apologize and will add you in a later volume of the Chronicle.

In one other respect this Chronicle is different from what went before. It is divided into separate books of around 120 pages each since the new material would have made a single atlas too large. Each volume will be published individually and the series will end when I can no longer continue it, so there is no predetermined number of volumes. These smaller books are self-published as the previous publisher did not wish to produce a second edition of the atlas, and because it allows me more flexibility.

This volume begins before the start of the 'Space Age' and ends as the Surveyor and Lunar Orbiter programs are beginning.

Phil Stooke
Victoria, British Columbia, January 2025.

Spacecraft image credits:

Lunar Reconnaissance Orbiter camera (LROC) data: NASA/GSFC/Arizona State University, and Robinson, M.S., *et al.* (2010). Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview, *Space Science Reviews*, v. 150, pp. 81-124. <https://doi.org/10.1007/s11214-010-9634-2>

Lunar Reconnaissance Orbiter Laser Altimeter (LOLA): Smith, D.E., Zuber, M.T., Jackson, G.B. *et al.*, 2010. The Lunar Orbiter Laser Altimeter investigation on the Lunar Reconnaissance Orbiter mission. *Space Science Reviews*, v. 150, pp.209-241. <https://doi.org/10.1007/s11214-009-9512-y>

Lunar QuickMap (<https://quickmap.lroc.asu.edu>), developed by NASA, Arizona State University and Applied Coherent Technology Corp.

Luna: All Luna images, maps derived from them and any other material originating from the Soviet Union were provided courtesy of V. V. Shevchenko, Director, Sternberg State Astronomical Institute, Moscow and his colleagues. These materials were not copyrighted.

Lunar Orbiter: NASA/JSC, Lunar and Planetary Institute (<https://www.lpi.usra.edu/resources/lunarorbiter/#support>), Lunar Orbiter Image Recovery Project: (<https://catalog.archives.gov/id/77811149>)

Ranger: Ranger images were obtained from the NSSDCA website and <https://www.lpi.usra.edu/resources/ranger/>

Surveyor: Surveyor images used in the Chronicle were scanned by the author at the Lunar and Planetary Institute, the Lunar and Planetary Laboratory of the University of Arizona and at the U.S. Geological Survey in Flagstaff, Arizona.

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Reference maps

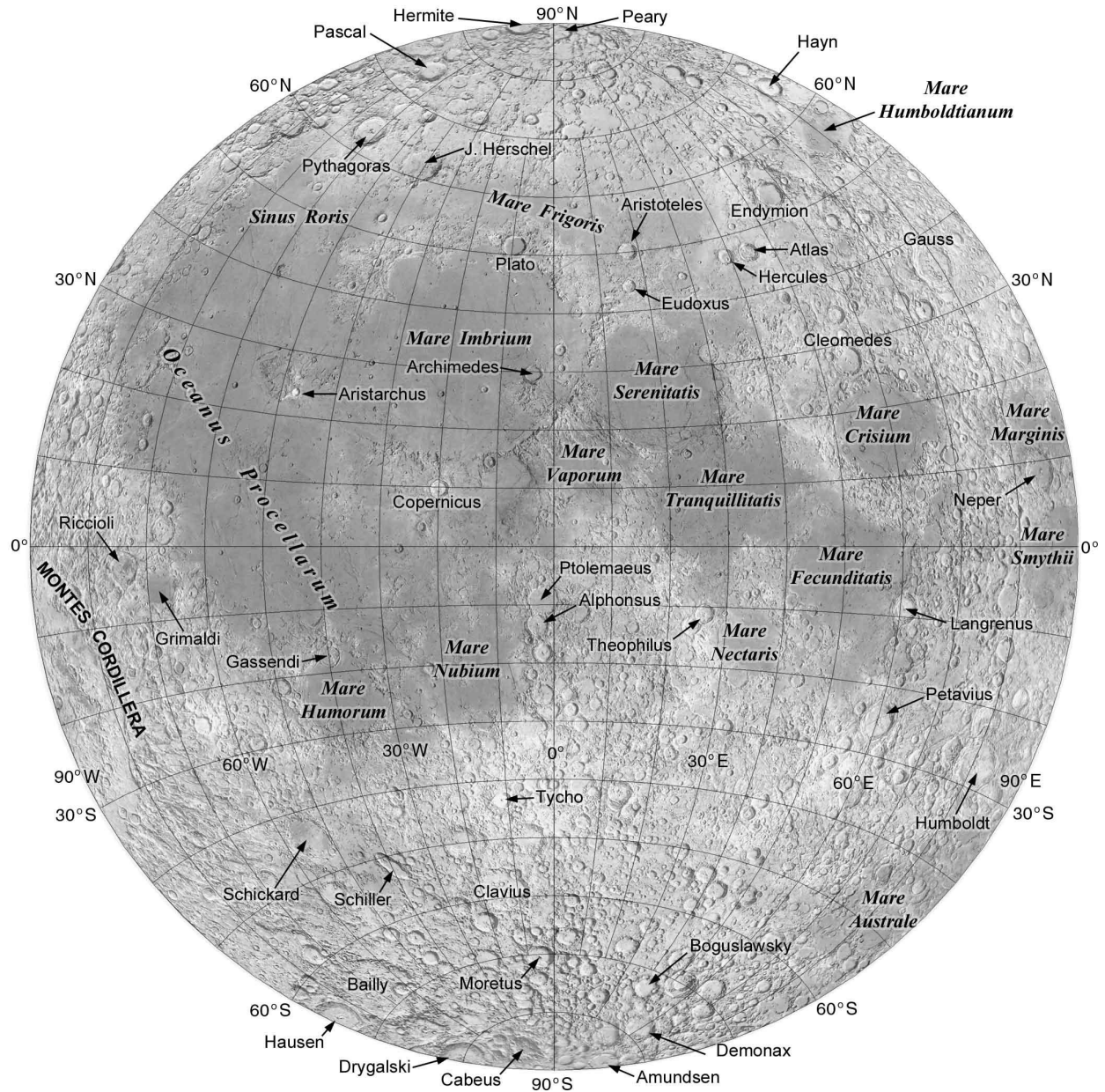


Figure 1. The lunar nearside, showing some of its major features. The map images for Figures 1, 2 and 3 are composites of a U.S. Geological Survey shaded relief map and a Clementine image mosaic, combined and modified as described in the text by P. Stooke. The map projection is Azimuthal Equidistant.

Reference maps

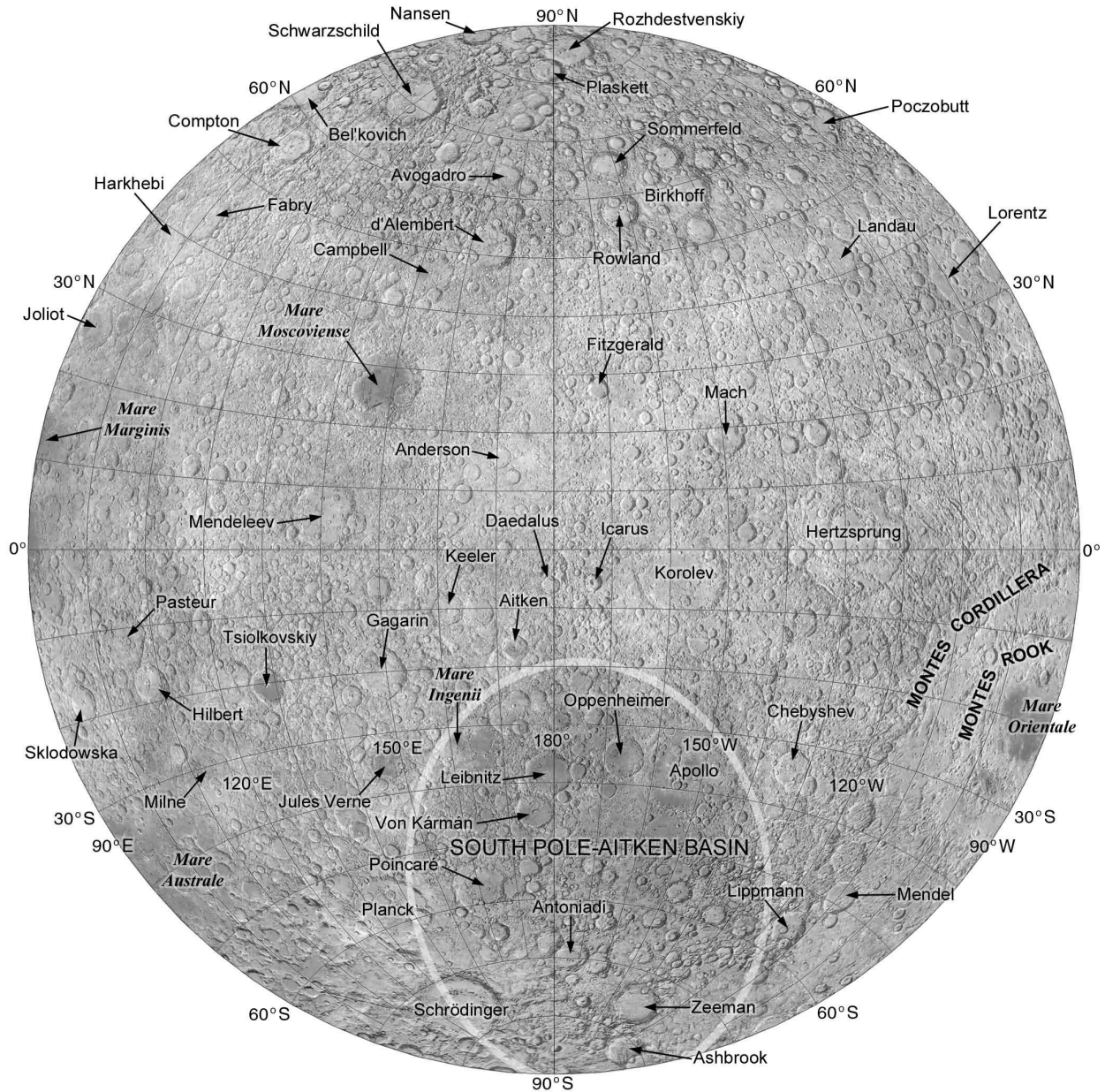


Figure 2. The lunar farside, with some of its major features. Note in particular the South Pole-Aitken Basin (white ellipse) which extends from the south pole to the crater Aitken near the centre of the map. The basin (a basin is a very large crater) was not known to exist during the period covered in this volume of the Chronicle, though its low albedo interior was hinted at in the first images of the farside.

Figures 1 and 2 show the major features of the lunar surface to help place other maps in context. Figure 3 shows the spacecraft landing and known impact sites covered in this book, which are also listed in Table 16 at the end of the book. The base map is a composite of a shaded relief drawing created by the U.S. Geological Survey and a global mosaic of Clementine images to highlight dark plains and bright crater rays. Polar regions omit the Clementine mosaic to avoid excessive shadowing, and a small area around the crater Cabeus has been augmented with data from LRO. The grid lines are 10° apart and the grid spacing represents approximately 300 km (200 miles) on the lunar surface, measured north to south or along the equator. The map projection is Azimuthal Equidistant. These maps or sections of them are used throughout the atlas to provide global or regional context for maps of smaller areas.

The Moon's diameter is 3476 km, 27% that of Earth. The nearside (also called the Earthside) always faces Earth (Figure 1). Lunar longitude is defined so that 0° longitude is, on average, at the centre of the lunar disk as seen from Earth. The nearside is dominated by the dark basalt plains called *maria* (singular *mare*), easily visible from Earth without a telescope. The western half of the nearside is dominated by Oceanus Procellarum, the largest mare area, roughly 1500 km across. The first robotic landings took place in this region. The eastern half of the nearside contains several smaller maria, including Mare Tranquillitatis, site of the first Apollo landing in 1969. It also includes the region where three small samples of lunar soil were acquired by Russian spacecraft in the 1970s. Further south and around the edge of the map area, the landscape is dominated by rugged uplands covered with impact craters.

The farside (Figure 2) always faces away from Earth and was almost completely unknown before the space age. An apparent wobbling motion of the Moon, called *libration*, allows the fringes of the farside to be glimpsed through telescopes on Earth, though not very clearly because of the severe foreshortening at the limb (edge of the disk). The lack of large maria on the farside is readily apparent here, but the small Mare Moscoviense stands out in the northwest, and small patches of dark material are seen in the southeast in Mare Australe and the dramatic crater Tsiolkovsky.

The southern half of the farside contains two of the most dramatic features on the Moon. A large, slightly darker region near the bottom of Figure 2 is the South Pole-Aitken (SPA) basin, the oldest, largest and deepest impact basin still preserved on the Moon. The word 'basin' is used for the largest craters, especially those showing concentric ring structures like those of Orientale. SPA takes its name from two features which roughly define its extent, the south pole and the large crater Aitken near the equator. The name is frequently confused in popular accounts, leading to expressions like 'the Aitken basin at the south pole'. Its cratered floor may look superficially similar to the cratered highlands which pervade the rest of the farside, but this is deceptive. The region is chemically distinct from its surroundings, and the giant impact or later impacts within it may have excavated material from the bottom of the lunar crust or even its mantle, the rock layer beneath the crust.

The Orientale basin, a small dark mare area surrounded by concentric mountain ranges and inward-facing scarps, lies on the eastern edge of the farside. It is partly on the western edge of the nearside (Montes Cordillera on Figure 1 outline the edge of the basin), as we would describe it now, but lunar longitudes were reversed relative to Earth's before the 'space age' to suit astronomical terminology. They were switched to correspond to terrestrial usage soon after spacecraft exploration began, so on older maps Mare Orientale was on the eastern edge of the nearside, hence its name. This was the last of the very large impact basins formed on the Moon, and the best preserved. The lunar surface is covered with craters of all sizes, showing that impact has been by far the dominant geological process on the Moon. Small craters tend to be bowl-shaped but larger craters often have a central peak, sometimes a cluster of peaks or mountains. They merge with basins at diameters over c. 250 to 300 km as the central peak becomes a 'peak ring' and the characteristic concentric structure of a basin becomes apparent. If a central peak is not visible in a large crater (e.g. Archimedes, Plato) it has most likely been buried under other material.

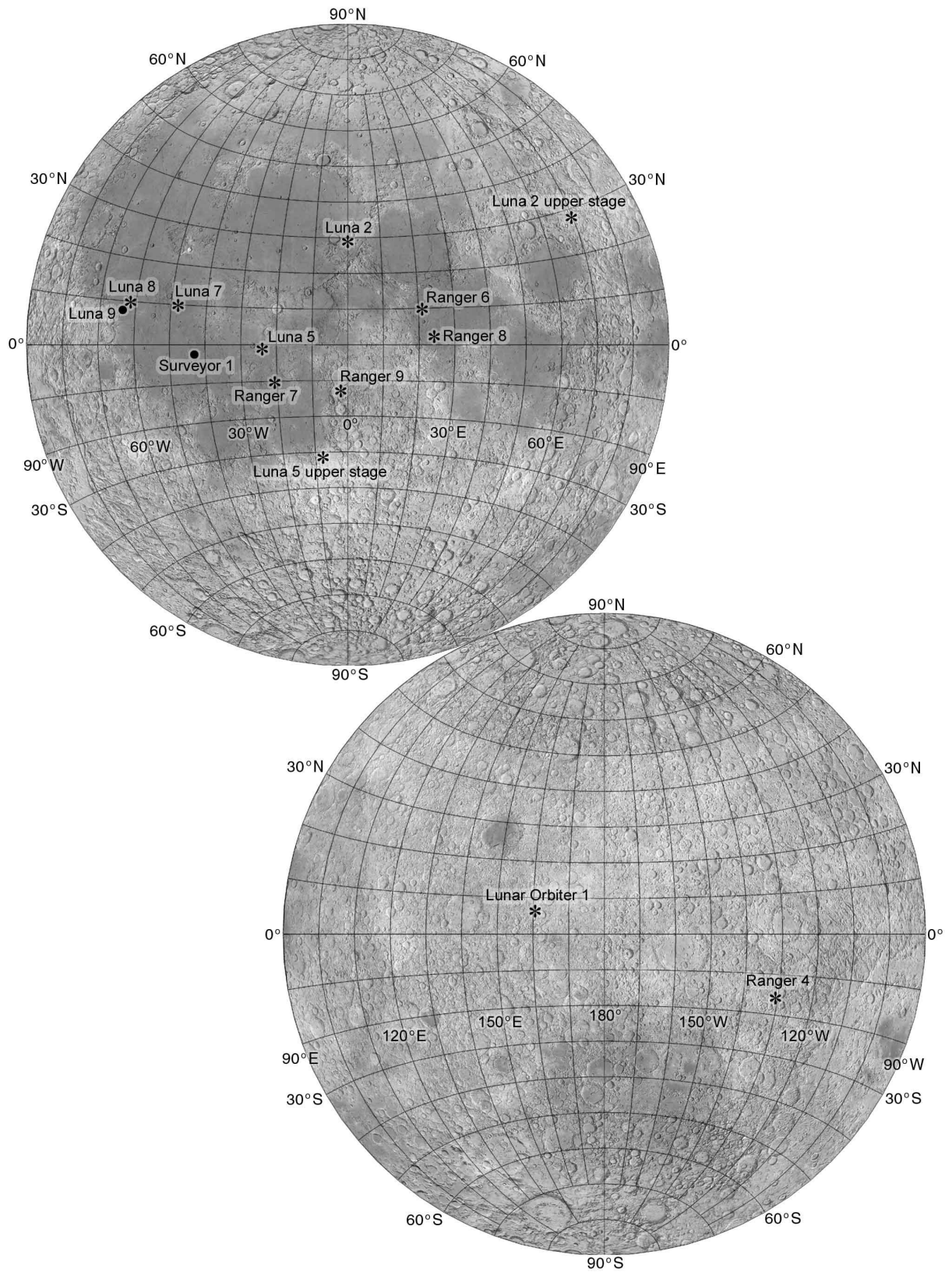


Figure 3. Landing or impact sites of spacecraft described in this volume. A dot is a landing site, an asterisk is an impact site.

The Moon at the dawn of the Space Age

The Moon has been scrutinized for thousands of years, but by the middle of the 20th Century the apparently dead grey world had long ceased to interest most professional astronomers. Maps already showed as much detail as telescopes could reveal, the lunar landscape seemed never to change, and its light interfered with observations of more scientifically stimulating objects in the deeper sky. But opinions evolve. The Moon became the goal of a great technological and political competition, not for its own sake but to show which of two competing superpowers would, in President John F. Kennedy's words, "become the world's leading space-faring nation", and to impress people around the world who were "attempting to make a determination of which road they should take". Inevitably as this new world was studied more closely, scientists – most of them geologists rather than astronomers - found much to interest them. Lunar science was reborn during the Space Age.

From the perspective of the 21st Century, it is easy to forget how little was known when the Space Age began. The Moon had never been seen at close range. Its farside had never been seen at all, beyond almost useless glimpses of the libration zone, the area just beyond the edges of the nearside. This can be glimpsed intermittently as the Moon appears to 'wobble' slightly during its orbit around the Earth. Scientific measurements of the Moon's composition, detailed spectral characteristics, internal structure, magnetism and gravity had never been made. Moon rocks already on Earth in the form of meteorites were not recognised as such because there was nothing to compare them with. All these advances became possible as a direct result of exploration since 1959, most of which occurred over a mere two decades.

The nearside had been mapped by astronomers for over three hundred years, more if we consider attempts to portray its markings before the invention of the telescope (Whitaker, 1999). Nevertheless, the lunar maps available in the first half of the twentieth century were far from adequate for detailed exploration. Features smaller than one kilometre across were not reliably shown, systematic information on heights of hills or depths of craters was not available, and only the most rudimentary geological mapping had been attempted. Many geological interpretations of this period (*e.g.* that most craters were volcanic, that the nearside was scribed with a rectilinear grid of tectonic structures, that crater rays were sites of condensed gases emanating from impact-induced fractures) have been abandoned. There was widespread disagreement over the level of volcanic activity. Were lunar craters produced by impact or volcanic activity? Were the flat plains lava or dust deposits? This began to change as a handful of geologists, most notably Eugene Shoemaker, compared lunar craters and the few impact craters then known on Earth with artificial explosion craters, including those produced in nuclear tests (Wilhelms, 1993).

The nearside could be mapped using telescopes (Figure 4), but the farside was almost completely unknown. The libration zones had been glimpsed only under conditions which made them very difficult to study. Nevertheless, a few hints emerged. None of the large maria extended across the limb (the edge of the disk) into the farside. This suggested that the distribution was not random or uniform, and that there were few or no large maria on the farside. Fresh craters such as Tycho and Copernicus were surrounded by rays, long bright streaks made of, or caused by, debris thrown out of the craters as they formed. A few could be traced over the limb, suggesting where fresh craters might be found on the far side (Figure 5).

The history of lunar mapping is described by Kopal and Carder (1974) and Whitaker (1999). Figures 4 to 6 illustrate some of the maps available in the early years of the Space Age. When the United States Army and Air Force were considering lunar military outposts (Figures 9B, 9C), the Army Map Service (which became part of the U.S. Army Topographic Command, and later the Defense Mapping Agency) and the U.S. Air Force Aeronautical Chart and Information Center (ACIC) respectively produced maps to support their studies. The same agencies later supported NASA's Apollo planning. ACIC maps are shown in Figure 4. An Army map is shown in Figure 6C. At the same time researchers at the U. S. Geological Survey (USGS) attempted to dissect the visible surface into its constituent layers of different materials and determine their sequence and modes of formation, based on photointerpretation methods devised by Eugene Shoemaker and his colleagues (Wilhelms, 1990).

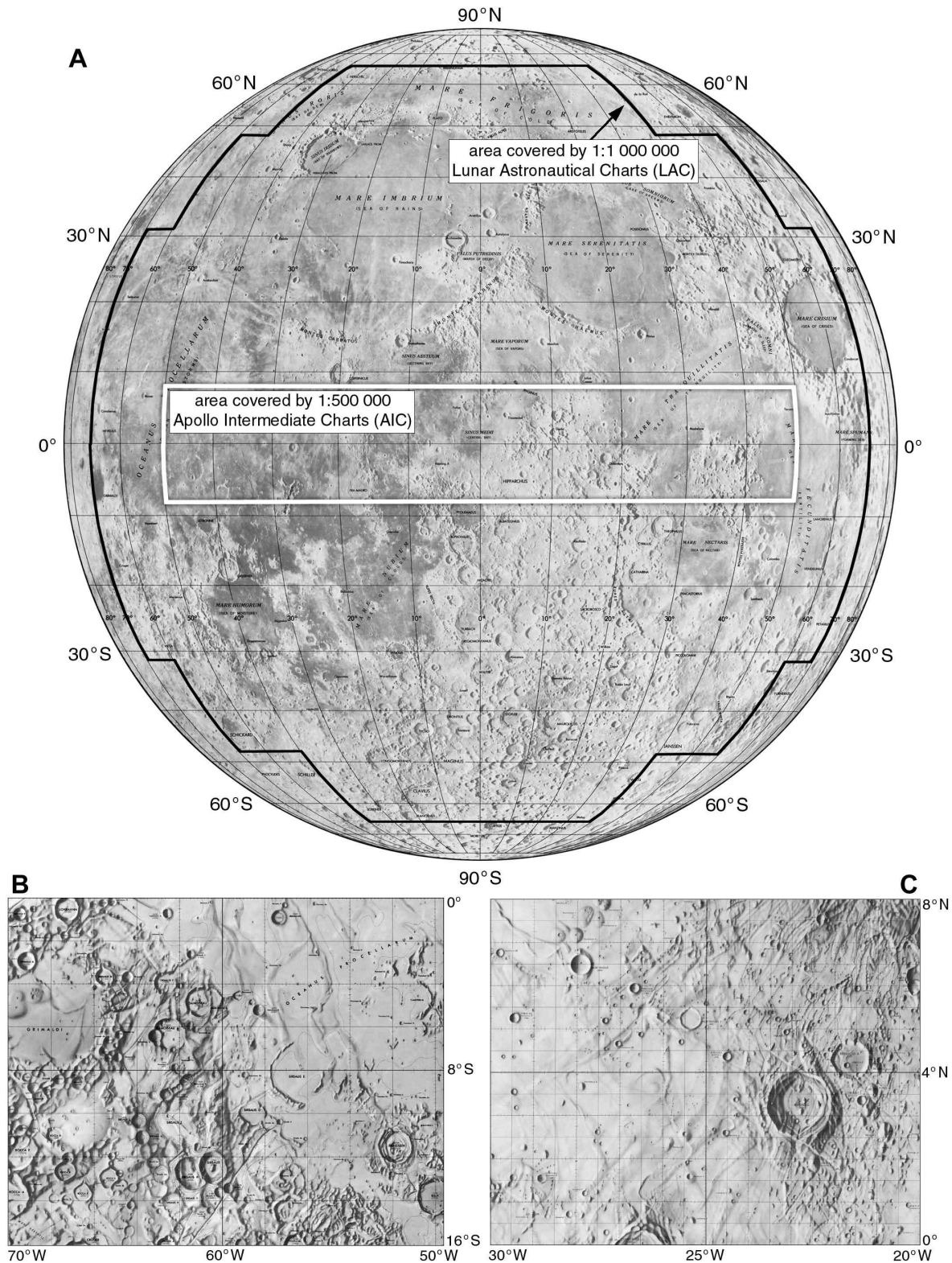


Figure 4. U. S. Air Force lunar mapping. 4A: Coverage of ACIC charts produced for Apollo between 1960 and 1969. The area inside the black outline was mapped at 1:1 000 000 scale in LACs (4B). The white outline shows the area covered by of AICs at 1:500 000 scale (4C). Figure 4B is LAC 74 (*Grimaldi*), 1st Edition, April 1962. Figure 4C is AIC 58D (*Reinhold*), 1st Edition, March 1965.

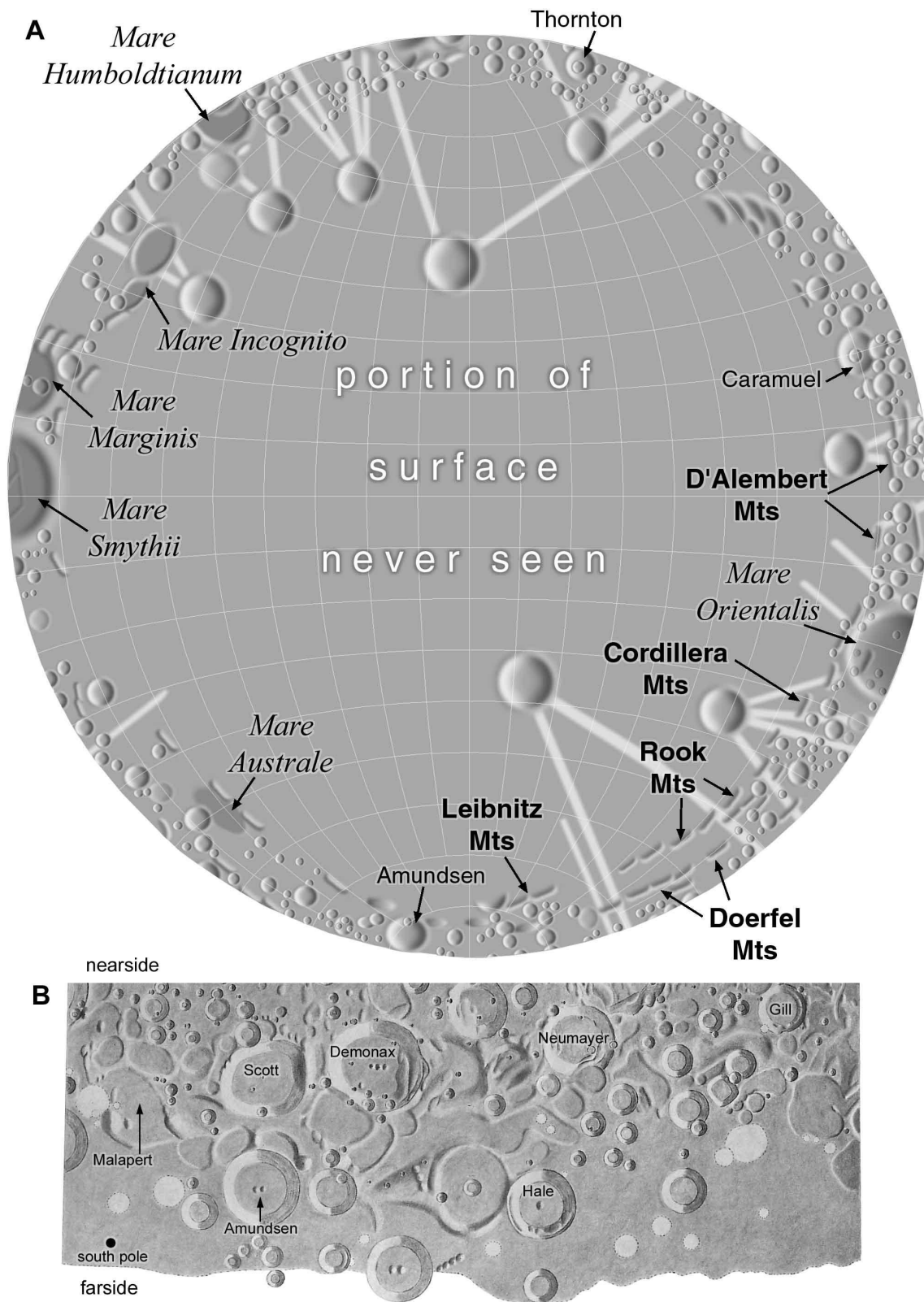


Figure 5: Glimpses of the farside. 5A: libration zone and ray-tracing maps based on Wilkins and Moore (1955) and Fielder (1959). 5B: drawing by Alika Herring of the libration region near the south pole (Herring, 1965), courtesy LPL Library.

Figure 4A shows the nearside coverage of maps produced by the U.S. Air Force Aeronautical Chart and Information Center (ACIC). The base map is the Lunar Reference Mosaic (ACIC chart LEM-1A, Lunar Earthside Hemisphere, 3rd Edition, July 1967, original scale 1:10 000 000). The Lunar Astronautical Charts (LAC) covered most of the nearside away from the limb regions on 44 sheets at a scale of 1:1 000 000 (one millimetre represents one kilometre). Most of them, except those at the edge of the mapped region, included elevation contours estimated from stereoscopic imaging by telescope and measurements of the lengths of shadows cast by hills and crater rims. The Apollo Intermediate Charts (AIC) represented the limits of effective telescopic mapping at the time and covered only the primary zone of interest for early Apollo landings on 20 sheets at a scale of 1:500 000.

The very limited knowledge of the farside shown in Figure 5 is a composite of the only sources of information available prior to the first spacecraft missions: the libration zone around the edge, and crater ray extrapolations into the unseen region (Wilkins and Moore, 1955; Fielder, 1959). A little later Alicka Herring at the Lunar and Planetary Laboratory in Tucson, Arizona made a more detailed study of the libration zone (Herring, 1965). This was quickly superseded by spacecraft imaging, leaving only a very small area near the south pole unmapped until 1990.

Gerard P. Kuiper of the University of Arizona was a pioneer of lunar and planetary studies in the years leading up to the Space Age. At the University of Chicago prior to 1960, while professional interest in the Moon languished, he published the first of a series of important photographic lunar atlases. His assistants included D. W. G. (Dai) Arthur and Ewen A. Whitaker, and later others including William Hartmann and Charles Wood. One important innovation of Kuiper's was the rectification of limb photographs by projection onto a blank globe. This made possible an undistorted view of the limb regions for the first time and resulted in the discovery of the great concentric ring structures of the Orientale basin (Hartmann and Kuiper, 1962).

Figure 6 illustrates some other early maps which assisted with preparations for lunar exploration. The American maps show parts of the region around Copernicus where the first NASA impact probes were intended to reach the surface, and where geological relationships were first worked out. The Soviet map shows the region around Mare Crisium and Mare Fecunditatis where several robotic sample return missions landed.

A pioneering geological analysis in support of U. S. Army lunar planning was made by U.S. Geological Survey (USGS) scientists Robert Hackman and Arnold Mason (1961). Figure 6A is a detail of the Physiographic Divisions map from this study, which assessed landing and operational conditions over the nearside. The geological interpretation methods pioneered by Eugene Shoemaker are illustrated in Figure 6B, a detail from Eggleton (1965). Figure 6C is part of a 1967 U. S. Army Map Service map.

Gerard Kuiper took two Lick Observatory photographs to Moscow, where a group of military cartographers working under Lev Bugaevsky combined them with other images to create the photomap shown in Figure 6D (Photomap of the Visible Side of the Moon, original scale 1:5 000 000, by the Sternberg State Astronomical Institute, 1967). Professor Yuri N. Lipsky and colleagues at several institutes in Moscow also contributed to this and other lunar maps including the first farside maps (Figures 12, 38A). Soviet cartographers also produced a strip of 1:1 000 000 scale maps along the nearside equator where their human landings were expected to occur. These were largely adapted from the LAC maps.

Rocketry pioneer Robert H. Goddard made numerous statements concerning lunar exploration in the years around 1920 (Goddard and Pendray, 1970). He suggested that a rocket might hit the Moon, targeted for a mare region and carrying flash powder to create a brief light flash visible against the dark background, to prove contact had been made. He suggested that cameras might be carried to the vicinity of both the Moon and Mars for scientific study. Finally he proposed that an observatory could be set up on the lunar surface, with a crew sustained by a greenhouse. A polar location would provide near-continuous lighting for the greenhouse and power plant. Water of crystallization in lunar minerals might survive in cold polar locations long after it had been baked out of lower latitude sites, and permanent shadows would create low temperatures to help liquify the hydrogen and oxygen for use as rocket fuel. Infrastructure would be protected from micrometeorites by covering it with regolith. Although he was wrong about the nature of the water, his other thoughts about lunar bases were commonly held by the end of the century, and other sources of water in these regions were found later.

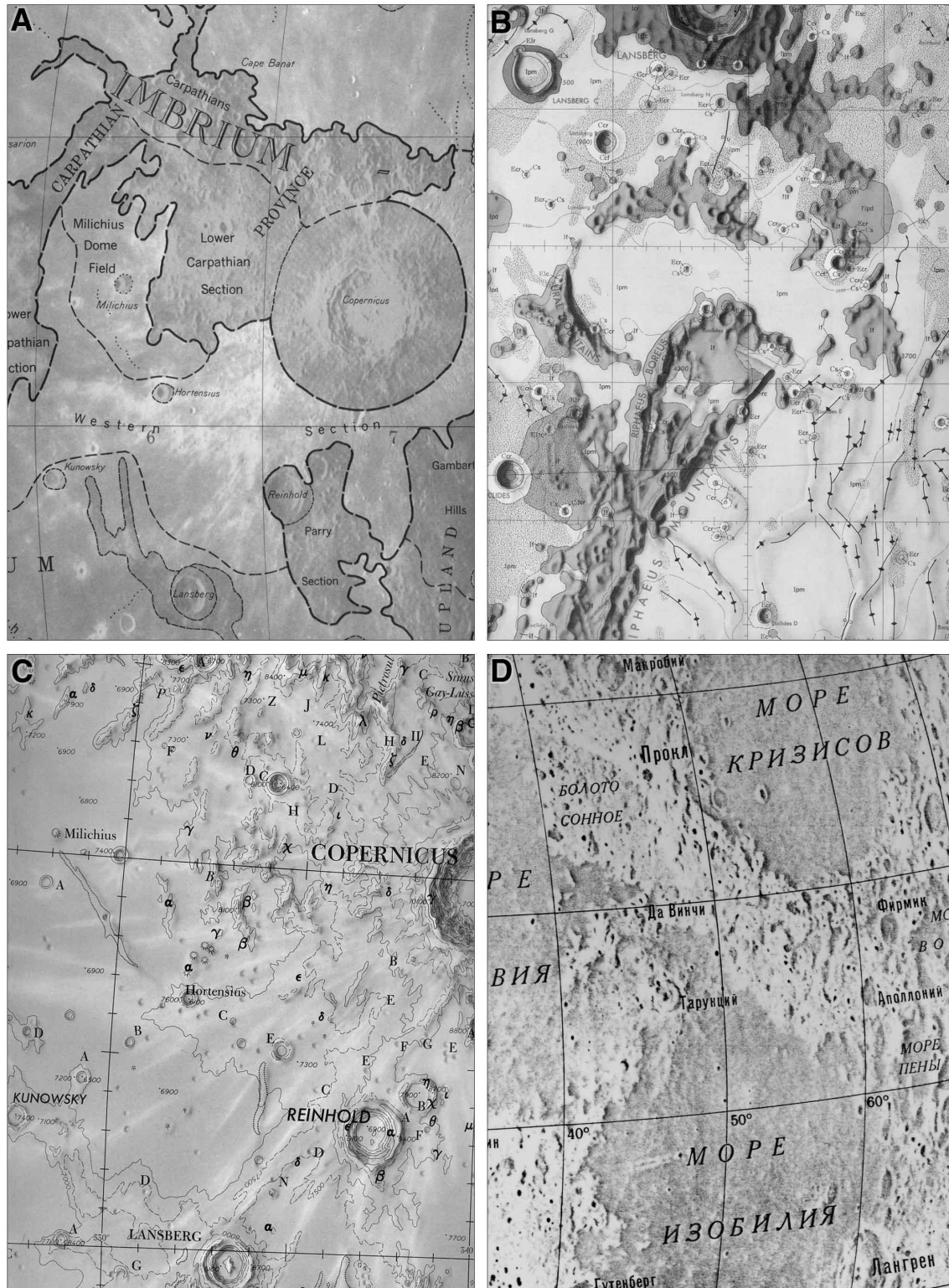


Figure 6: Lunar maps of the 1960s. 6A: Engineer Special Study of the Surface of the Moon (1961). 6B: Geological map (Eggleton, 1965). 6C: Topographic map (U. S. Army Map Service, 1967). 6D: Photomap of the Visible Side of the Moon, original scale 1:5 000 000, Sternberg State Astronomical Institute, 1967.

William John Bray, a communications engineer with the Post Office Research Station in London, U. K., suggested in 1940 that radio signals might be reflected off the lunar surface and received on Earth (Katz and Franco, 2011). The first successful reflections were obtained as part of the U. S. Army Signal Corps' Project Diana on 10 January 1946 at Fort Monmouth, New Jersey under the direction of John H. DeWitt. This evolved into the Communication Moon Relay project (Operation Moonbounce) which was able to establish effective communication links, including between Hawaii and Washington, D.C. in 1960. The development of artificial satellite relays, first suggested by Arthur C. Clarke (1945) quickly rendered Operation Moonbounce obsolete. Amateur radio operators have continued reflecting signals off the Moon. In October 2009 visual artist Daniela de Paulis and the CAMRAS radio amateurs association based at Dwingeloo radio telescope in the Netherlands developed a new application of Moonbounce, called Visual Moonbounce, which allowed moonbouncing images.

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Early Lunar Mission Concepts

A variety of possible lunar missions were described, some in considerable detail, in the decade preceding Sputnik 1. Those which specified landing points are summarized in Table 1 and illustrated in Figure 7.

The British Interplanetary Society was one of several amateur rocket and spaceflight clubs set up between the World Wars. Others were established in Germany and Russia. A paper by H. E. Ross read to the Society on 13 November 1948 detailed a plausible lunar landing mission. Three spacecraft would enter Earth orbit, each carrying one pilot. The crew would transfer to one ship which would refuel from the other two. One would then be discarded while the other was fueled with the surplus not needed by the first. The crewed spacecraft would travel to the Moon, enter orbit, detach its fuel tanks and descend to the surface. To return to Earth the vehicle would rendezvous with the fuel

tanks, refuel, and enter a transearth trajectory. The returning spacecraft would rendezvous with the remaining vehicle in Earth orbit and the crew would transfer to that vehicle to land.

In 1946 M. H. Wholey proposed a landing near the craters Archimedes, Aristillus and Autolycus. In 1951 the film *Destination Moon*, based on a story by Robert A. Heinlein, placed its landing site at the crater Harpalus. Two years later Wernher von Braun and Willy Ley proposed landing slightly to the west of Harpalus in Sinus Roris. Also in that year, 1953, G. V. E. Thompson and H. P. Wilkins proposed a list of candidate sites including six craters and eleven mare sites (Table 1, Figure 6). In 1954 A. C. Clarke and R. A. Smith suggested landing in Mare Imbrium 8 km west of Mons Piton. These proposals are summarized by Parkinson and Smith (1979).

In another paper Wilkins (1954) proposed that lunar expeditions land in any of several large flat-floored craters. They were smooth enough for a safe landing but were surrounded by interesting features. The maria were mostly seen as too bland to be interesting. Wilkins thought that crews would make the final site selection based on orbital observations after they arrived, as prior mapping by robotic spacecraft was not anticipated. He suggested the craters Stöfler, Schomberger, Pontecoulant, and Schickard in the south, Ptolemaeus, Grimaldi, Billy, and Vendelinus near the equator, and Plato, Endymion, Anaximander, Meton, Archimedes, Otto Struve, Euler, and Condorcet in the north. The only mare site he now considered was Sinus Medii. The scenario developed by Stewart (1961) called for a landing and extensive surface traverses from Piazz Smyth, 100 km northwest of Piton in Mare Imbrium (Figures 7B, 7C). Stewart also mentions a suggestion by Eric Burgess in 1952 for a landing in Palus Putredinis. Only the last of these suggestions, near the Apollo 15 landing site, came close to being visited by astronauts.

Table 1. Early suggestions of possible landing sites

(including only sites with specified coordinates in Parkinson and Smith, 1979, p. 60 and Stewart, 1961)

date	proposer	number on map	description	location
1946	Wholey	1	Archimedes, Aristillus, Autolycus	33° N, 2° W
1951	<i>Destination Moon</i> film	2	Harpalus	53° N, 43° W
1953	von Braun and Ley	3	Sinus Roris, overland trek to Harpalus	54° N, 46° W
1953	Thompson and Wilkins	4	Mare Crisium	18° N, 58° E
		5	Mare Fecunditatis	4° S, 51° E
		6	Mare Nectaris	14° S, 34° E
		7	Mare Tranquillitatis	9° N, 30° E
		8	Mare Serenitatis	30° N, 17° E
		9	Mare Frigoris	56° N, 4° E
		10	Mare Imbrium	36° N, 16° W
		11	Mare Vaporum	14° N, 5° E
		12	Mare Humorum	23° S, 38° W
		13	Oceanus Procellarum	10° N, 47° W
		14	Sinus Iridum	45° N, 32° W
		15	Grimaldi	6° S, 68° W
		16	Schickard	44° S, 53° W
		17	Schiller	52° S, 40° W
		18	Tycho	43° S, 11° W
		19	Clavius	59° S, 15° W
		20	Maginus	50° S, 5° W
1954	Clarke and Smith	21	8 km west of Piton, Mare Imbrium	41° N, 2° W
1961	Stewart	22	Piazz Smyth, Mare Imbrium	42° N, 3° W

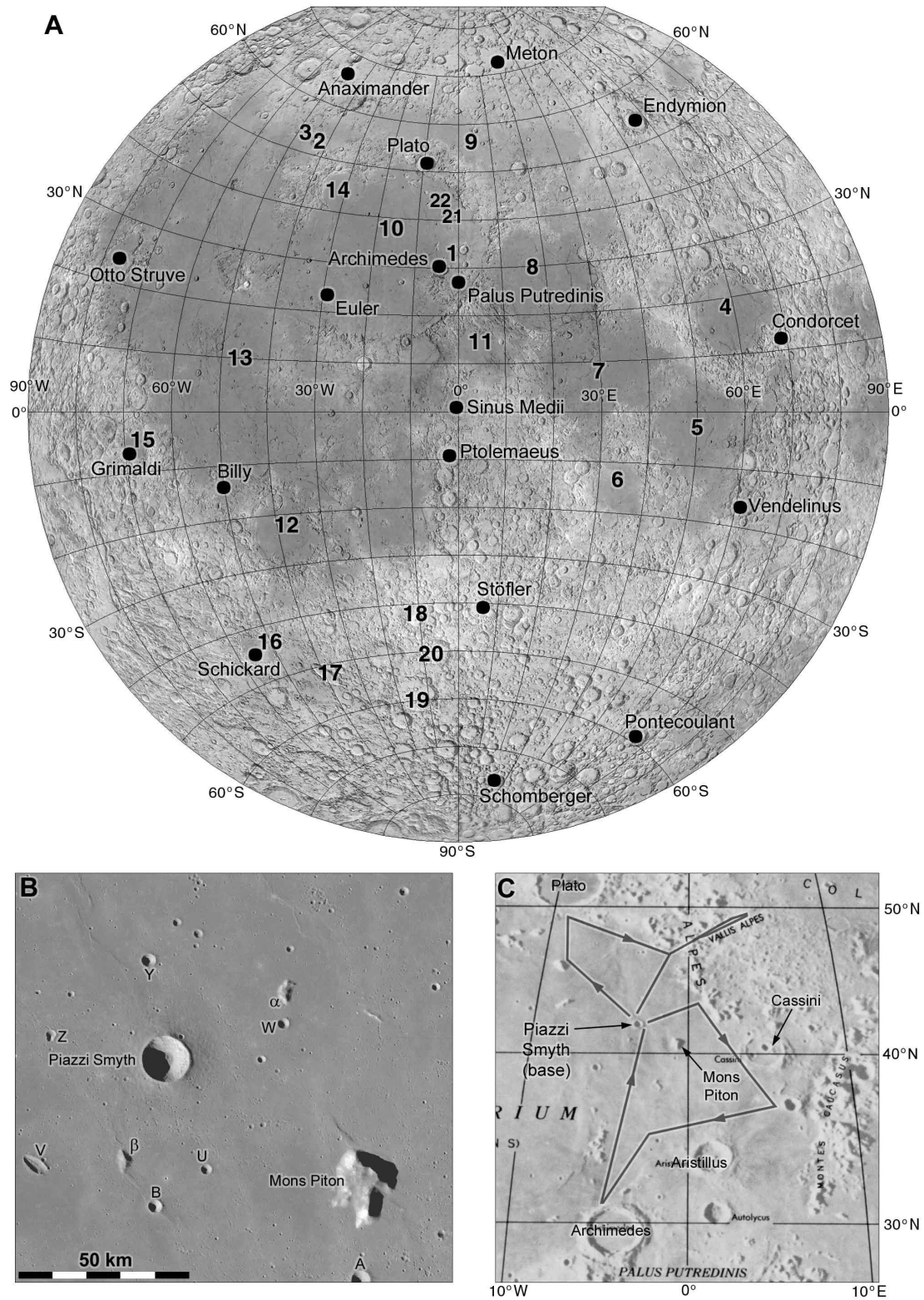


Figure 7. The earliest suggested landing sites. 7A: numbers are sites listed in Table 1. Circles with names are other sites mentioned in the text. 7B: Base camp area for Stewart's 1961 expedition. The image is part of an LROC wide angle mosaic. 7C: Stewart's surface traverses. The base map is from Figure 4A.

Stewart's mission would begin with supplies and a return vehicle soft-landed ahead of the crew, in 1968 or 1969. In 1970 the crew would land in several rockets and in the first lunar day set up a base in Piazzzi Smyth crater (Figure 7B), an observatory, and a radar beacon and radio relay on top of Mons Piton. During the second and third lunar days two teams would use large, tracked vehicles to undertake geological expeditions to Plato and the Alpine Valley, and to Cassini, Aristillus and Archimedes craters, picking up extra supplies landed previously along the route (Figure 7C, plotted on a detail of Figure 4A). Some travel would be by earthlight during the lunar night.

Parkinson, B. and Smith, R. A., 1979. *High road to the Moon; from imagination to reality*. London: British Interplanetary Society.

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Wilkins, H. P., 1954. Where to land on the Moon, *Journal of the British Interplanetary Society*, Vol. 13, March 1954, pp. 65-67.



1957: Rocket around the Moon

Before Sputnik and the anticipated U. S. satellite Vanguard 1, German-American rocket pioneer Krafft Ehricke and Soviet-American physicist George Gamow suggested that the next obvious target after Earth orbit would be the Moon (Ehricke and Gamow, 1957). They suggested that a satellite called Cow (because it would 'jump over the Moon'), weighing several hundred kg, could be launched as early as 1963 into a highly elliptical orbit reaching just beyond the Moon. It would be timed to pass the lunar surface at a distance of about 2000 km, where it would collect photographs on film and other data on the environment at lunar distances and then return to Earth, entering the atmosphere protected by its heat shield. The Soviet Union's Zond 5, 6, 7 and 8 spacecraft eventually followed mission profiles like this in 1967, 1969 and 1970.

A second lunar mission would use two probes to collect a sample from the lunar surface. The first probe would deploy an atomic bomb onto the Moon to eject a debris cloud high above the surface. The second probe would pass through the cloud, collecting some of the debris, and return it to Earth. Although this plan was never followed, versions of this mission strategy with inert impactors rather than bombs have been proposed for sample return missions to other worlds including the Martian satellites and Jupiter's Moon Europa.

Ehricke, K. and Gamow, G., 1957. A Rocket Around the Moon. *Scientific American*, v. 196, no. 6, June 1957, pp. 47-53.



17 August 1958: Thor-Able 1

Thor-Able 1, built by Space Technology Laboratories (TRW) and sometimes called Pioneer 0, was designed to orbit the Moon carrying a payload for the International Geophysical Year (IGY) research program. It was part of the U.S. Air Force's Operation Mona, conducted by the Air Research and Development Command's Ballistic Missile Division under the direction of the Advanced Research Project Agency (ARPA). Subsequent missions were turned over to the newly formed National Aeronautics and Space Administration (NASA). The spacecraft was launched from Cape Canaveral at 12:18 UT but was destroyed 77 seconds after launch at 16 km altitude over the Atlantic when its Thor booster exploded.

The lunar observations would have been the first photographs of the farside, and information on the magnetic field and dust environment of near-lunar space. The illuminated area available for photography (Figure 8A) would have included nearly half of the far side, if images had been taken soon after arrival.

The spin-stabilised, battery-powered spacecraft was cylindrical with a wide conical cap on each end, the whole structure 76 cm long and 70 cm in diameter, weighing 38 kg. The instruments were an infrared imaging system, a magnetometer, a micrometeorite detector and engineering sensors. The scanning camera built up an image one line at a time as spacecraft rotation swept the sensor field of view across the target. Each line was displaced across the target by the spacecraft's motion along its path. The spacecraft was sterilized to avoid contaminating the Moon in the event of an accidental impact.

At the farthest point of its very elongated orbit about the Earth, roughly 65 hours after launch and 300 000 km from Earth, while travelling roughly parallel to the Moon's orbit but slower than the Moon, a small solid-fuel rocket was intended to fire on command from Earth on 20 August at 02:18 UT. This would increase the spacecraft velocity to match that of the Moon, putting it in an erratic and ill-defined high lunar orbit with a period of up to seven days



23 September 1958: Luna 1958A

This first Soviet Luna spacecraft was designed by Sergei Pavlovich Korolev's Experimental Design Bureau No. 1 and launched from Baikonur at 07:03 UT. It was destroyed when its launch vehicle broke up about 90 seconds after liftoff due to severe vibrations in the fuel lines, probably caused by the strap-on boosters. The goal was to achieve the first spacecraft impact on the Moon. The target was near the center of the lunar disk as seen from the approaching spacecraft (Figure 8B). The target areas for this and later Luna impact probes are estimated from the intended trajectories and Soviet reports on the target region for Luna 2. The approach path, from the north and to the east of the Earth-Moon line, dictated the approximate target area, which moved north or south with the changing declination of the Moon (a more southerly declination giving a more northerly target point). Soviet spacecraft were not assigned mission numbers unless they were launched successfully, so an official designation was saved for the first successful deep space flight in 1959.

Soviet lunar probes had been authorised by an official decree 'Concerning work on automated lunar probes and three-stage launch vehicles for them' issued on 20 March 1958. Rumours had surfaced earlier in the western press concerning an attempt to impact a probe on the Moon on 1 May 1958, a public holiday in the Soviet Union. Launch would have been about two days earlier (Anonymous, 1958). No other details are available, and the report may have derived from preliminary plans which were later rescheduled, without any launch attempt having being made at that time. *Aviation Week* later reported (Clark, 1959) that such launch attempts were conducted almost monthly during 1958, with some probes being equipped with warheads to create an explosion visible on Earth as a means of proving that the mission had succeeded. The reports of launches were incorrect, an example of faulty intelligence common during the Cold War, but the idea of causing a nuclear explosion on the Moon was initially considered by both superpowers.

The Luna spacecraft was a pressurized 360 kg sphere 120 cm in diameter with four antennae protruding from one side. Internal air circulation cooled the instruments to about 20°C. Instrument ports also projected from the surface of the sphere. It had no propulsion system. Like Luna 1 it probably carried several metallic emblems with the Soviet coat of arms to be deposited on the lunar surface. The spacecraft instruments probably consisted of a magnetometer, two radiation detectors, micrometeorite and interplanetary gas detectors, and engineering sensors.

Anonymous, 1958. First lunar shot to seek far side data. *Aviation Week*, v. 69, no. 5, 4 August 1958, p. 26.

Clark, E., 1959. Soviet Moon success follows failures. *Aviation Week*, v. 70, no. 2, 12 January 1959, pp. 26-28.

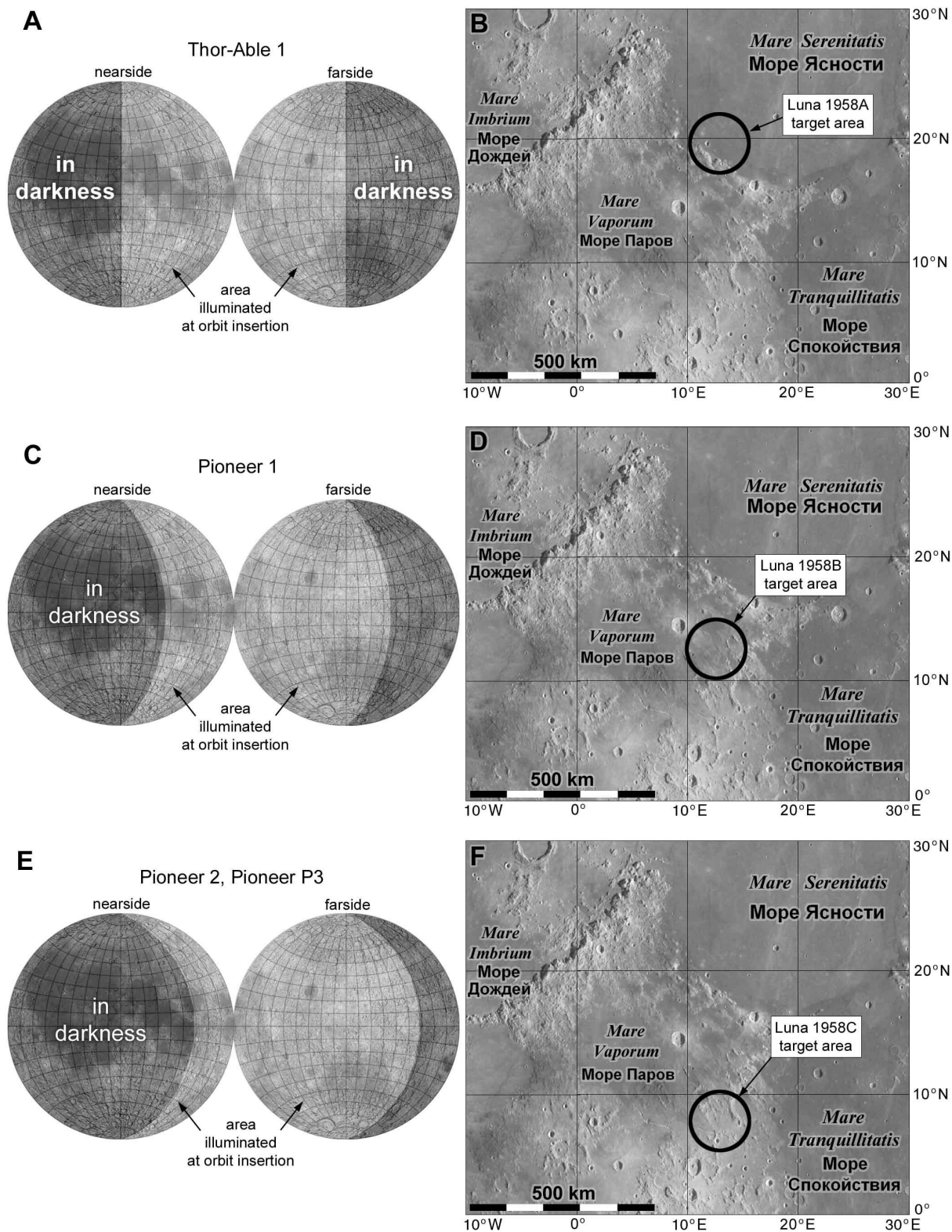


Figure 8: Sunlit areas and target points for the first lunar missions. 8A: Illumination conditions for Thor-Able 1 imaging. 8B: Luna 1958A target area. 8C: Figure 10. Illumination conditions for Pioneer 1 imaging. 8D: Luna 1958B target area. 8E: Illumination conditions for Pioneer 2 and the later Pioneer P3 imaging. 8F: Luna 1958C target area. The base map for Figures 8B, 8D and 8F is an LROC wide angle mosaic.



11 October 1958: Pioneer 1

Pioneer 1, manufactured by TRW, was almost identical to Thor-Able 1 and was the first spacecraft launched by NASA. Following the loss of the earlier spacecraft, ARPA had transferred control of the Army and Air Force lunar programs back to the two separate armed services, to be operated for NASA. Pioneer 1 was intended to study radiation, cosmic rays, magnetic fields and micrometeorites near Earth and in lunar orbit, and to photograph the Moon. It would have entered a very high (60 000 km) lunar orbit and made images intermittently over ten days or about three orbits. If it had succeeded, about two thirds of the far side could have been photographed at the time of arrival (Figure 8C).

Launch was from Cape Canaveral at 08:42 UT, but a programming error in the Thor launcher's upper stage resulted in insufficient velocity and the spacecraft followed a sub-orbital trajectory, reaching a maximum altitude of 114 000 km. Pioneer 1 returned some data on the extent of the Earth's radiation belts and made the first measurements of micrometeorite numbers and the interplanetary magnetic field. It re-entered over the South Pacific Ocean after 43 hours at 03:46 UT on October 13. Pioneer 1's instrument package weighed 18 kg and contained a scanning infrared television camera to photograph the lunar farside, a radiation detector, a micrometeorite detector, a magnetometer and engineering sensors to record the spacecraft's internal conditions, slightly improved from the Thor-Able 1 package (Anonymous, 1958).

Anonymous, 1958. Lunar probe stages, flight plan. *Aviation Week*, v. 69, no. 16, 20 October 1958, p. 32.



11 October 1958: Luna 1958B

The goal of this second Soviet lunar mission was again a lunar impact. The launch was from Baikonur at 21:42 UT, but the launcher disintegrated 104 seconds later due to vibrations caused by the strap-on boosters. The spacecraft and instruments were identical to the previous launch. This Luna was launched only a few hours after Pioneer 1, but because Luna was on a faster trajectory, it would have reached the Moon first. The intended impact site was again near the center of the lunar disk as seen from the approaching spacecraft (Figure 8D).



8 November 1958: Pioneer 2

Pioneer 2 was launched from the Atlantic Missile Range on a Thor-Able booster at 07:30 UT, by the Air Force for NASA. The spacecraft was intended to study the Moon and nearby space but failed to reach escape velocity when the third stage did not fire after an apparently successful separation. It flew a sub-orbital trajectory reaching a maximum altitude of 1550 km, and re-entered the atmosphere at 28.7° N, 1.9° E over NW Africa 6 hours 52 minutes after launch. Some measurements were obtained, including the radiation flux and energy and the micrometeorite density above the equatorial region. Pioneer 2 was almost identical to Pioneer 1. The instrument package weighed 16 kg and consisted of an improved television system, two radiation counters, a micrometeorite detector, a magnetometer and engineering sensors. The camera aperture was moved from the cylindrical instrument section to the aft conical cap. The lunar observations would have been photographs of most of the farside (Figure 8E, and radiation and magnetic field measurements (Anonymous, 1958). Figure 8 shows that each successive Pioneer spacecraft would have been able to image a greater fraction of the farside if it had been successful.

Anonymous, 1958. Army plans two Moon shots next month. *Aviation Week*, v. 69, no. 20, 17 November 1958, pp. 28-30.



4 December 1958: Luna 1958C

This Luna spacecraft, identical to the previous vehicle, was intended to impact the Moon. The launch from Baikonur at 17:18 UT was unsuccessful. The booster's core engines shut off 245 seconds after liftoff because of a loss of lubrication to the oxidizer pump. The intended impact site was again near the center of the lunar disk as seen from the approaching spacecraft (Figure 8F). Figure 8 shows that the general target area for each Luna launch varied as the lunar declination at the time of arrival changed.



6 December 1958: Pioneer 3

Pioneer 3 was a lunar probe built by the U.S. Army under the direction of NASA. It was launched from the Atlantic Missile Range, Cape Canaveral, at 05:45 UT on a Juno II rocket. It was intended to carry a scientific payload close to the Moon 34 hours after launch, and then enter solar orbit. Plans to impact the lunar surface were also considered. The mission failed when the booster's first stage shut down too early. Pioneer 3 reached an altitude of approximately 110000 km and returned data showing that Earth's radiation belt consisted of at least two distinct bands. It re-entered the atmosphere over northern Africa at 19:51 UT on 7 December at an estimated location of 16.4° N, 18.6° E.

The spacecraft was conical with a height of 58 cm and a base 25 cm in diameter. The fibreglass cone was coated with gold to conduct electricity and was painted with white stripes to help maintain moderate internal temperatures. Batteries at the base of the cone powered the instruments and a small antenna at the tip of the cone. Twin light sensors at the centre of the base would indicate when the probe passed about 30 000 km from the Moon. In the original design, they would have triggered a camera to take a single 30 km resolution film image of the farside which would be developed, scanned and transmitted to Earth. The camera was later replaced with a 6 kg scientific payload containing a radiation meter, but the light sensor was retained. The spacecraft was spin-stabilised at 400 rpm after launch, but its rotation would be slowed to six rpm ten hours after launch when two small weights were spooled out to the ends of two wires, each 1.5 m long. The weights and wires would then be released (Clark, 1958).

Clark, E., 1958. Radiation belt explored by Army's Pioneer III probe. *Aviation Week*, v. 69, no. 24, 15 December 1958, pp. 28-31.



2 January 1959: Luna 1

The first nearly successful lunar probe, the Soviet Union's Luna 1 was launched from Baikonur at 16:41 UT. It was intended to hit the lunar surface but passed about 6000 km from the Moon's western limb at 02:57 UT on 4 January after 34 hours of flight because it had a slightly excessive velocity and a small directional error. At 00:57 UT on 3 January, 113000 km from Earth, the launch vehicle's upper stage released a cloud of sodium gas which was visible

for several minutes in the constellation Virgo with the brightness of a sixth-magnitude star, allowing astronomers in Kazakhstan to track the spacecraft. It also allowed study of the behavior of gases in space. Luna 1 entered an orbit around the Sun with a period of 443 days, mostly between the orbits of Earth and Mars, and was tracked for 62 hours out to about 600 000 km. The booster's third stage stayed close to Luna 1 and shared its fate.

Luna 1 was initially called The Cosmic Rocket, later The First Cosmic Rocket and Mechta ('Dream') and in the west 'Lunik 1' (a phonetic allusion to Sputnik), and was referred to by some Soviet scientists as 'Planet Ten' after entering solar orbit. Its target area on the Moon was at the center of the disk as seen from the approaching spacecraft (Figure 9A). The spherical Luna 1 carried several metallic emblems with the Soviet coat of arms which it was supposed to deposit on the lunar surface. The launch was dedicated to the upcoming 21st Congress of the Communist Party of the Soviet Union. The spacecraft instruments consisted of a magnetometer, two radiation detectors, a micro-meteorite detector, and engineering sensors. The measurements obtained by Luna 1 provided data on the Earth's radiation belt, showed that the Moon had no strong global magnetic field and detected the solar wind, a flow of ionized particles from the Sun which pervades interplanetary space (Anonymous 1959a, 1959b).

Luna 1 is usually said to be the first artificial object to exceed Earth's escape velocity, though there was a possible precursor (Clark, 1959). Two small aluminium pellets propelled by a shaped explosive charge carried on a U.S. Air Force Aerobee rocket launched from Holloman Air Force Base, New Mexico, may have exceeded escape velocity on 16 October 1957, though they carried no instruments and the rocket reached an altitude of only about 90 km. This was a test of a concept in which projectiles would strike the Moon at high velocity in order to obtain data on surface composition from the spectrum of the resulting flash (Zwicky, 1961).

Anonymous, 1959a. Soviets detail Lunik instruments. *Aviation Week*, v. 70, no. 3, 19 January 1959, p. 28.
Anonymous, 1959b. Mechta telemetry, instruments detailed. *Aviation Week*, v. 70, no. 26, 29 June 1959, p. 53.
Clark, E., 1959. Soviet Moon success follows failures. *Aviation Week*, v. 70, no. 2, 12 January 1959, pp. 26-28.
Zwicky, F., 1961. Possible operations on the Moon. *Spaceflight* v. 3, no. 5, September 1961, pp. 177-179.



5 February 1959: Working Group on Lunar Exploration

This NASA planning group met for the first time on this date at JPL to prepare advice for NASA on lunar exploration (Newell, 1973). The group was chaired by NASA's Robert Jastrow, and included Harold Urey (then at the University of California at San Diego, UCSD), Frank Press of Caltech, Jim Arnold of UCSD, and Harrison Brown of Caltech. Jastrow had been advising NASA on the development of space science in the new agency (formed only 6 months earlier on 29 July 1958), and Urey convinced him of the importance of lunar exploration, which now seemed within reach. The work of this group laid the foundation for the Ranger, Surveyor and Apollo missions of later years.

Newell, H. E., 1973. Harold Urey and the Moon. *The Moon*, v. 7, nos. 1/2, March-April, 1973, pp. 1-5.



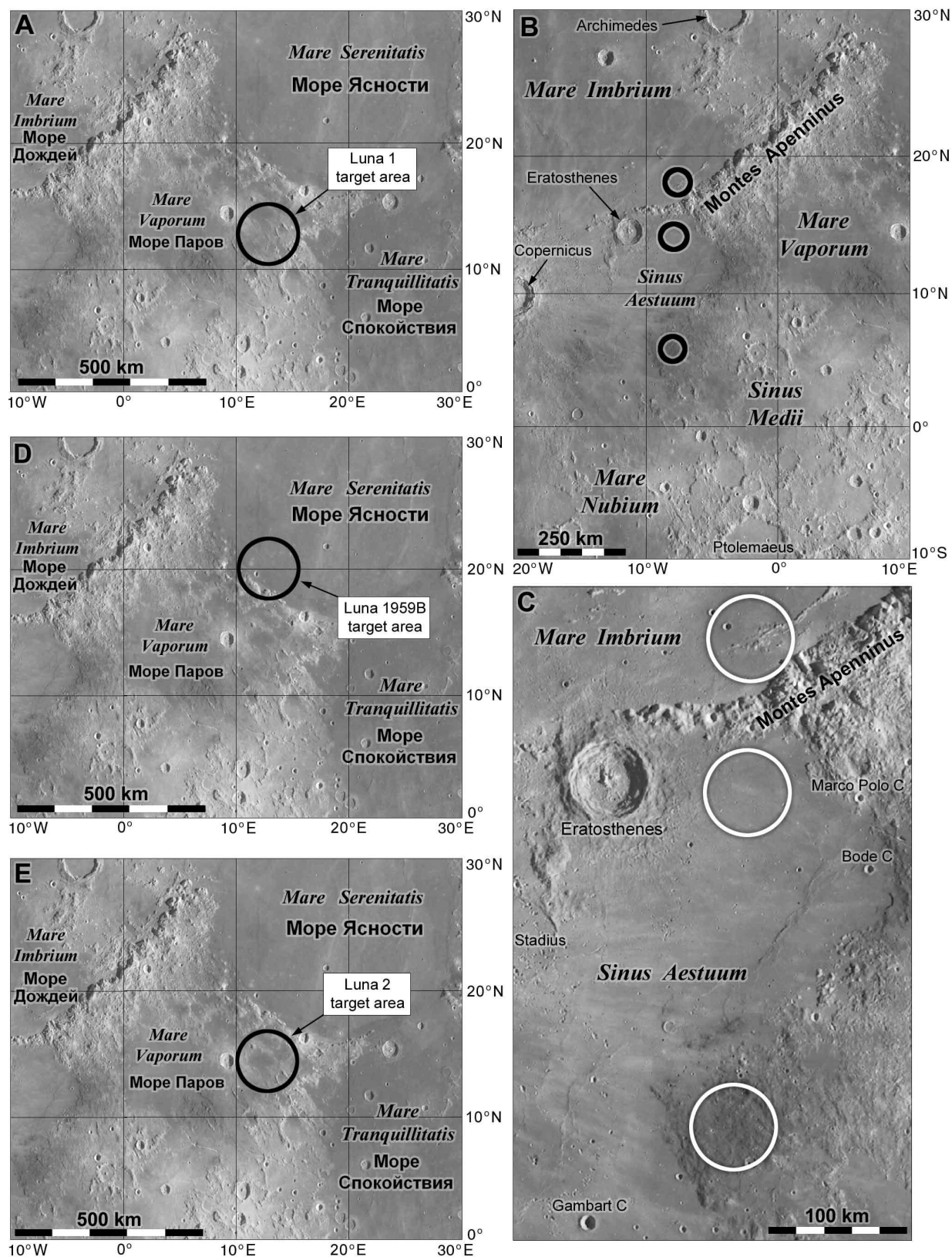


Figure 9. Luna mission targets and Project Horizon sites. A: Luna 1 target area. B, C: Project Horizon lunar base sites. D: Luna 1959B target area. E: Luna 2 target area. Base images are LROC wide angle mosaics.

3 March 1959: Pioneer 4

Pioneer 4, identical to Pioneer 3 in configuration, was a joint project of the Army Ballistic Missile Agency and Jet Propulsion Laboratory under the direction of NASA. It was launched at 17:11 UT from the Atlantic Missile Range on a Juno II rocket. Intended to pass about 25000 km from the Moon, it instead missed by 60000 km before entering a solar orbit with a period of 395 days. Pioneer 4 measured high-intensity radiation and provided a valuable tracking exercise. Its light sensor was unable to detect the Moon as it passed because of the unexpectedly large miss distance. The probe's closest approach to the Moon was over the location 5.7° S, 7.2° E on 4 March 1959 at 22:25 UT (5:25 p.m. EST) at a speed of 7230 km/hr. The probe was tracked for 82 hours out to 655,000 km from Earth and reached perihelion on 18 March 1959 at 01:00 UT. The cylindrical fourth stage casing (173 cm long, 15 cm diameter, 4.65 kg) went into solar orbit with the probe (Anonymous 1959a, 1959b).

Anonymous, 1959a. Pioneer probe passes Moon, orbits sun. *Aviation Week*, v. 70, no. 10, 9 March 1959, pp. 321-322;

Anonymous, 1959b. NASA reports data on Pioneer 4 orbit. *Aviation Week*, v. 70, no. 11, 16 March 1959, p. 32.



1959: U. S. Army and Air Force planning

Very early in NASA's existence plans began to be prepared for spacecraft to explore the Moon and planets. A very early example from JPL (Hibbs, 1959), prepared at NASA's request and drawing in part on earlier studies for the U. S. Army, proposed a series of missions to the Moon, Mars and Venus between 1959 and 1964. The plan combined scientific goals with engineering feasibility to identify necessary technical advances and to plan a reasonable series of missions capable of satisfying both scientific goals and public interest. Instruments would include both film and television cameras, magnetometers, particle and micrometeorite detectors and spectrophotometers for compositional studies. The report called for a program of three or four launches per year from 1960 to 1964. The lunar part of the program is outlined here.

The first mission in August 1960 was termed Lunar Miss, and would be an equipment and systems test during a lunar flyby. Following Venus and Mars flyby missions in the next few months, mission 4 would be a Lunar Rough Landing, a vehicle designed to land like the early Ranger capsules. It would launch in June 1961 and use a braking rocket to slow its capsule for a hard landing. A penetrometer would measure surface hardness and the lander would carry temperature sensors, fields and particles instruments and a seismometer. The lander would create a flash visible from Earth if it made a night landing or transmit a few descent images during a day landing. This would be followed in September 1961 by the fifth mission, the Lunar Satellite, an orbiter which would carry a gamma ray spectrometer to measure surface composition, cameras and particles and fields instruments. 1962 would be taken up with Venus and Mars orbiters and entry probes, and the next lunar probe would be in February 1963. This tenth mission, called Lunar Orbit and Return, would be an engineering test to demonstrate Earth return capability and the entry and operations of a future Venus soft lander. Mission 11 would be the Lunar Soft Landing in June 1963. A lander would study geology, temperature and gravity, deploy a seismometer and a magnetometer, and conduct a thorough landing site imaging survey. If possible at this time the lander would deploy a rover to study surface composition and physical characteristics at several locations chosen from the lander images, and again if possible a sample return might be achieved using small rockets.

The U. S. Air Force had its own very early plans including 'Man in Space Soonest', initiated in 1958 with an initial goal of putting an astronaut into low Earth orbit in 1960 and a future goal of landing an astronaut on the Moon in 1965 (e.g. U.S. Air Force, 1960). This would have included robotic lunar missions to examine the environment and surface. The first goal of this program eventually became the civilian Project Mercury.

Hibbs, A. R. (ed), 1959. *Exploration of the Moon, the Planets and Interplanetary Space*. Report no. 30-1. Pasadena: Jet Propulsion Laboratory, 30 April 1959.

U.S. Air Force, 1960. *Military Lunar Base Program / S.R. 183 Lunar Observatory Study*. v. 1, Study summary and program plan. Air Force Ballistic Missile Division, April 1960. ARDC project no. 7987, task no. 19769. <https://nsarchive2.gwu.edu/NSAEBB/NSAEBB479/docs/EBB-Moon03.pdf>



9 June 1959: Project Horizon

A lunar outpost was proposed by the U.S. Army on this date to protect potential United States interests on the Moon (Day, 2007; 2019). It would develop techniques for surveillance of Earth and space, for communications and for lunar surface operations. It would also serve as a base for exploration of the Moon, scientific investigations, more distant exploration and military operations if required.

Initially the outpost would be designed for a crew of 10 to 20 people on a sustained basis. It would be designed for simple expansion and re-supply, and rotation of personnel to ensure maximum extension of sustained occupancy, and to be self-sufficient for as long as possible without outside support. In the location and design of the base, consideration would be given to its operation as part of a space surveillance system, as a node for communication with and observation of Earth, as a station supporting travel between Earth and the Moon or to more remote locations, for scientific exploration, and for the defence of the base against attack if required. The primary objective was to establish the first permanent manned installation on the Moon. Incidental to this mission would have been the investigation of the scientific, commercial, and military potential of the Moon. The first piloted landing by two soldier-astronauts was targeted for April 1965 near a cluster of pre-landed cargo landers.

The exact location of the outpost site could not be determined until an exploratory probe and mapping program had been completed. However, for several technical reasons such as temperature and rocket energy requirements the area within 20° of the centre of the nearside seemed favourable. Nine locations were suggested, not all of which lay within the specified boundaries: Sinus Medii (southeastern part, or near Triesnecker crater). Sinus Aestuum (near Eratosthenes), Mare Imbrium (northwest of Copernicus, or northeast of Archimedes, or northeast edge of the Apennine mountains, or near Plato), Oceanus Procellarum (near Lansberg), Ptolemaeus crater (near Alphonsus), and Mare Nubium (southeast of Alphonsus). These east or west directions follow the old astronomical convention and should be reversed to apply to modern maps.

Within this area, three particular sites were chosen which appeared to meet the more detailed requirements of landing space, surface conditions, communications, and proximity to interesting features of different types. The report states that 'suitable sites for the outpost exist in the northern part of Sinus Aestuum, near Eratosthenes, in the southern part of Sinus Aestuum near Sinus Medii, and on the southwest coast of Mare Imbrium, just north of the [Apennines]' (U. S. Army, 1959). These areas are roughly located in Figures 9B and 9C. The southernmost site is shown in an area of dark pyroclastic deposits, and perhaps should be moved to the west, closer to the small crater Gambart C.

Day, D. A., 2007. Take off and nuke the site from orbit (it's the only way to be sure...). *The Space Review*, 4 June 2007. <https://www.thespacereview.com/article/882/1>.

Day, D. A., 2019. Nuking the site from orbit: when the Air Force wanted a base on the Moon. *The Space Review*, 4 November 2019. <https://www.thespacereview.com/article/3826/1>.

U. S. Army, 1959. *Project Horizon report. A U. S. Army study for the establishment of a lunar outpost*. 9 June 1959.



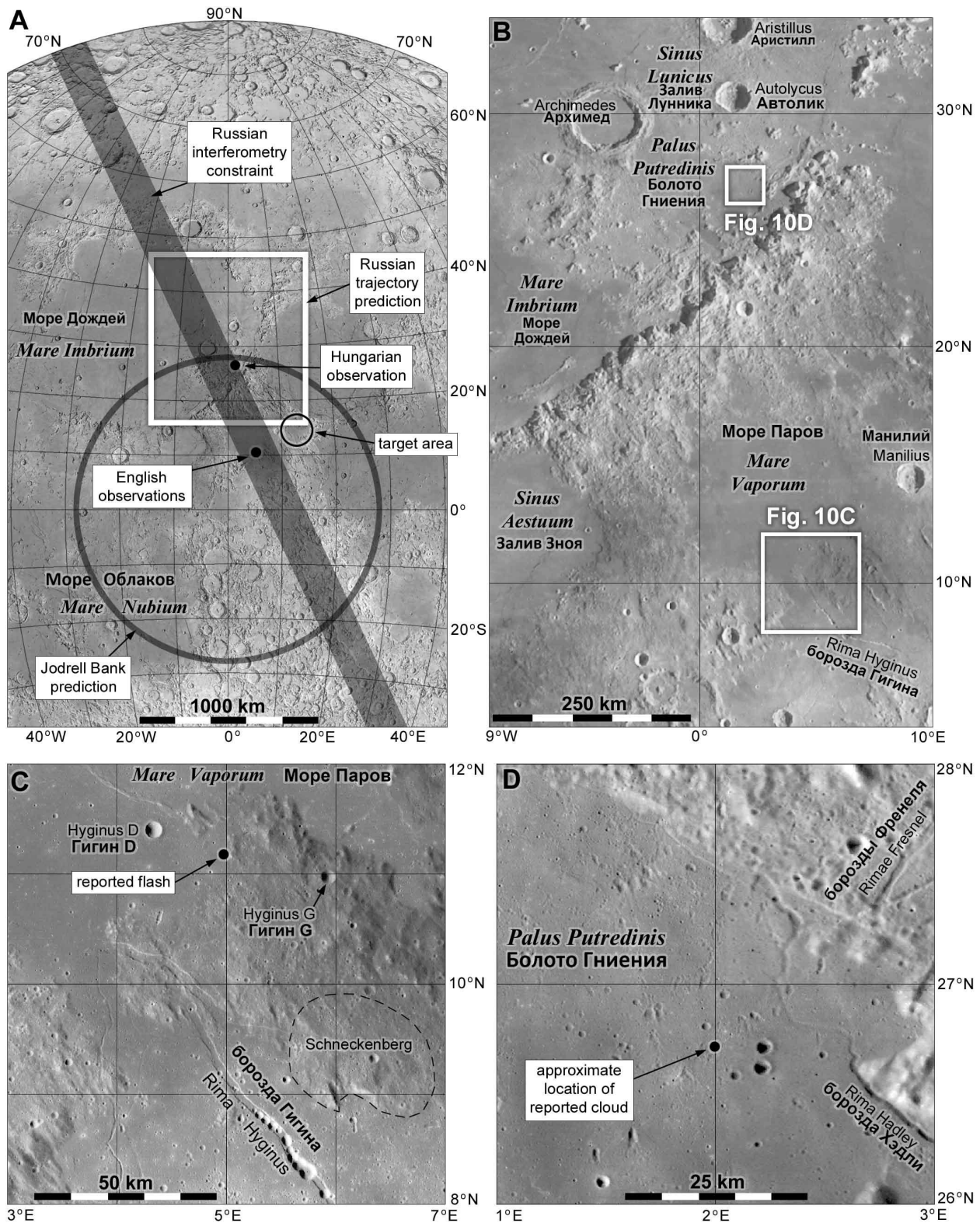


Figure 10. Luna 2 impact. A: context map showing the constraints on the impact location. B: locations of two purported visual sightings. C: reported sighting by Moore (1959) and Wilkins (1959). D: reported sighting from Konkoly Observatory, Hungary (Anonymous, 1960). C and D are LROC wide angle mosaics.

18 June 1959: Luna 1959B

This spacecraft was a modified version of the previous Luna design, and like its precursors it was intended to impact on the Moon. It was launched from Baikonur at 08:08 UT. The booster's inertial guidance system failed 153 seconds after launch and the vehicle was destroyed by the launch site safety officer. The intended impact site was near the center of the lunar disk as seen from the approaching spacecraft (Figure 9D).



12 September 1959: Luna 2

The 390 kg Luna 2, the first probe ever to impact the lunar surface, was launched from Baikonur at 06:39 after three aborted launch attempts in the previous four days. Like Luna 1, the spacecraft's upper stage rocket released an orange cloud of sodium gas to assist spacecraft tracking by telescope. Sodium metal was mixed with an explosive to create this discharge, which occurred 156 000 km from Earth at 18:39 UT on 12 September, appearing in the constellation Aquarius. The cloud expanded at 1 km per second and grew to 400 km diameter before fading to invisibility. The Soviet news agency Tass predicted in advance that the impact would occur in the region between the Maria Tranquillitatis, Serenitatis and Vaporum (Figure 9E). Luna 2 struck the Moon at 21:02 UT on 13 September in the area of Palus Putredinis after 33.5 hours of flight. Radio tracking from the United States, Japan, the United Kingdom and the Soviet Union and the abrupt end of radio transmissions indicated it had impacted on the Moon. Luna 2 delivered Soviet pennants to the surface of the Moon and confirmed that the Moon had no appreciable magnetic field or radiation belts (Clark 1959).

Luna 2 was similar in design to Luna 1, a 0.9 m diameter pressurized spherical spacecraft with protruding antennae and instrument parts. The instrumentation was also similar, including radiation detectors, a magnetometer, and micrometeorite detectors. There were no propulsion systems on Luna 2 itself. Luna 2 was also called the Second Cosmic Rocket and the Moon Rocket in the USSR, and Lunik 2 in the west. The official Luna designation was applied retroactively after the flight of Luna 3.

When initial trajectory data confirmed that Luna 2 would strike the Moon, a press release announced the expected time and location (Figure 9E). Mission directors wanted to be sure the claim of an impact would be accepted around the world, so they provided the radio transmission frequency and encouraged visual and radio observations. The ability of earthbound observers to see lunar impacts has been controversial. No Ranger or Apollo impacts were observed despite many attempts, and most western scientists doubted claims that the Luna 2 and Luna 5 impacts were seen. Only many years later and with much improved instrumentation were impacts such as those of SMART 1 and Kaguya seen unequivocally. If Luna 2 had launched on its first attempt on 6 September the target area would have been in darkness at the time of impact, but by 13 September the morning terminator was already 40° west of the target area and more than 20° west of the actual impact location.

Mitchell (2008) described efforts to locate the impact point. Tracking of the rocket and spacecraft suggested that the impact occurred in a 1000 km wide square centred at 29° or 30° N, 0° E. Those coordinates are often quoted without stating the very large uncertainty. Soviet scientists informed the Jodrell Bank Radio Observatory in Cheshire, U. K. of the expected impact time and the probe's radio frequency so their large steerable antenna, the largest in the world at the time, could track the impact. Analysis of the signal suggested an impact within 800 km of 0° N, 0° E, the centre of the lunar disk. Radio astronomers from the Lebedev Physical Institute in Moscow used antennae at the Simeiz Observatory in the Crimean Peninsula to measure the probe's position by radio interferometry. This system measured only one angle, constraining the impact site to within 150 km of a line. These constraints are mapped in Figure 10A. An area near the tracking location was named *Sinus Lunicus* (Zaliv Lunnikus on Russian maps) to commemorate this first direct contact with the Moon (Figure 10B).

In England the astronomer Patrick Moore noted a small flash at about 11.25° N, 4.88° E near the Schneckenberg, a hill north of Hyginus crater (Moore, 1959), an observation apparently confirmed by his colleague H. P. Wilkins who reported seeing a dark dust cloud after the flash (Wilkins, 1959). Both events were simultaneous but more than a minute after the expected impact time. Schneckenberg ('Snail Mountain') is an informal name assigned by Johann Krieger in the late 19th Century because ridges around the hill have a vaguely spiral pattern reminiscent of a snail's shell. At the Konkoly Observatory in Hungary, a dark expanding dust cloud was reported at the moment of impact, at about 26.7° N, 2.0° E (Anonymous, 1960). The English observations are near the target area but do not fit the tracking data. The Hungarian observation matches all constraints and may possibly be a reliable detection, but this is not universally accepted. These locations are mapped in Figures 10C and 10D.

About 30 minutes after Luna 2 struck the Moon the third stage of its rocket crashed at an unknown location. If the rocket followed essentially the same trajectory as the spacecraft the impact point would be displaced by the Moon's orbital motion, suggesting an impact somewhere near 27° N, 70° E (Figure 1). No contemporary estimate of the impact location has been found. This rocket also carried a commemorative Soviet pennant.

Anonymous, 1960. Lunik II's landing on the Moon. *Sky & Telescope*, v. 20, no. 5, November 1960, p. 265.
Clark, E., 1959. Soviets hit Moon, data flow improves. *Aviation Week*, v. 71, no. 12, 21 September 1959, pp. 28-30.
Mitchell, D. P., 2008. *Lunar Impact*. Published online at http://mentallandscape.com/L_Luna2.htm (accessed on 6 January 2025).
Moore, P., 1959. Untitled letter, *Nature*, v. 184, 15 August 1959, p. 502.
Wilkins, H. P., 1959. Untitled letter, *Nature*, v. 184, 15 August 1959, p. 502.



4 October 1959: Luna 3

Luna 3 was the first spacecraft to return images of the lunar farside. The 278 kg spacecraft was launched from Baikonur on an 8K72 booster at 02:24 UT on 4 October 1959. The spacecraft was spin stabilized in flight, but photoelectric cells and thrusters maintained a fixed orientation with respect to the Sun and Moon during photography. Its figure-eight trajectory passed over Earth's north pole, then 6200 km from the Moon near the south pole at 14:16 UT on 6 October 1959, and out over the farside. On 7 October 1959, 29 photographs taken over 40 minutes revealed 70% of the farside. The first was taken at 03:30 UT at a distance of 63 500 km, the last 40 minutes later from 66 700 km. The spacecraft resumed spinning, passed over a point near the Moon's north pole and looped back towards Earth. The images, taken on film, were developed, fixed and dried, and then 17 were scanned and successfully transmitted to Earth on 18 October 1959 as Luna 3 again approached Earth. Contact with the probe was lost on 22 October. The probe may have burned up in the Earth's atmosphere in March or April 1960 (possibly on 22 April), but might have survived in orbit until 1962 or later. The Luna 3 images were sufficient for the creation of the first useful map of the farside and the allocation of several placenames (Academy of Sciences of the USSR, 1960). The sophistication of the mission was remarkable for this early date. Luna 3 was referred to at the time as the Third Cosmic Rocket, and the Automatic Interplanetary Station. The Luna designation began to be applied retroactively to the first three Luna spacecraft soon after this flight.

The spacecraft was cylindrical with hemispherical ends, 130 cm long and 95 cm in diameter, 120 cm wide at a flange near one end. It was sealed and pressurized to 0.23 atmospheres. Solar cells on the exterior provided power to internal batteries. Thermal control flaps opened to radiate heat. The upper hemisphere held the cameras. Four antennae extended from the top of the probe, two from the bottom. Micrometeoroid and cosmic ray detectors were situated on the outside of the spacecraft, and attitude control thrusters outside at the lower end. The spacecraft had no maneuvering rockets. The interior held the camera, film processor and scanner, radio equipment, batteries, gyroscopes for attitude control, and fans for temperature control.

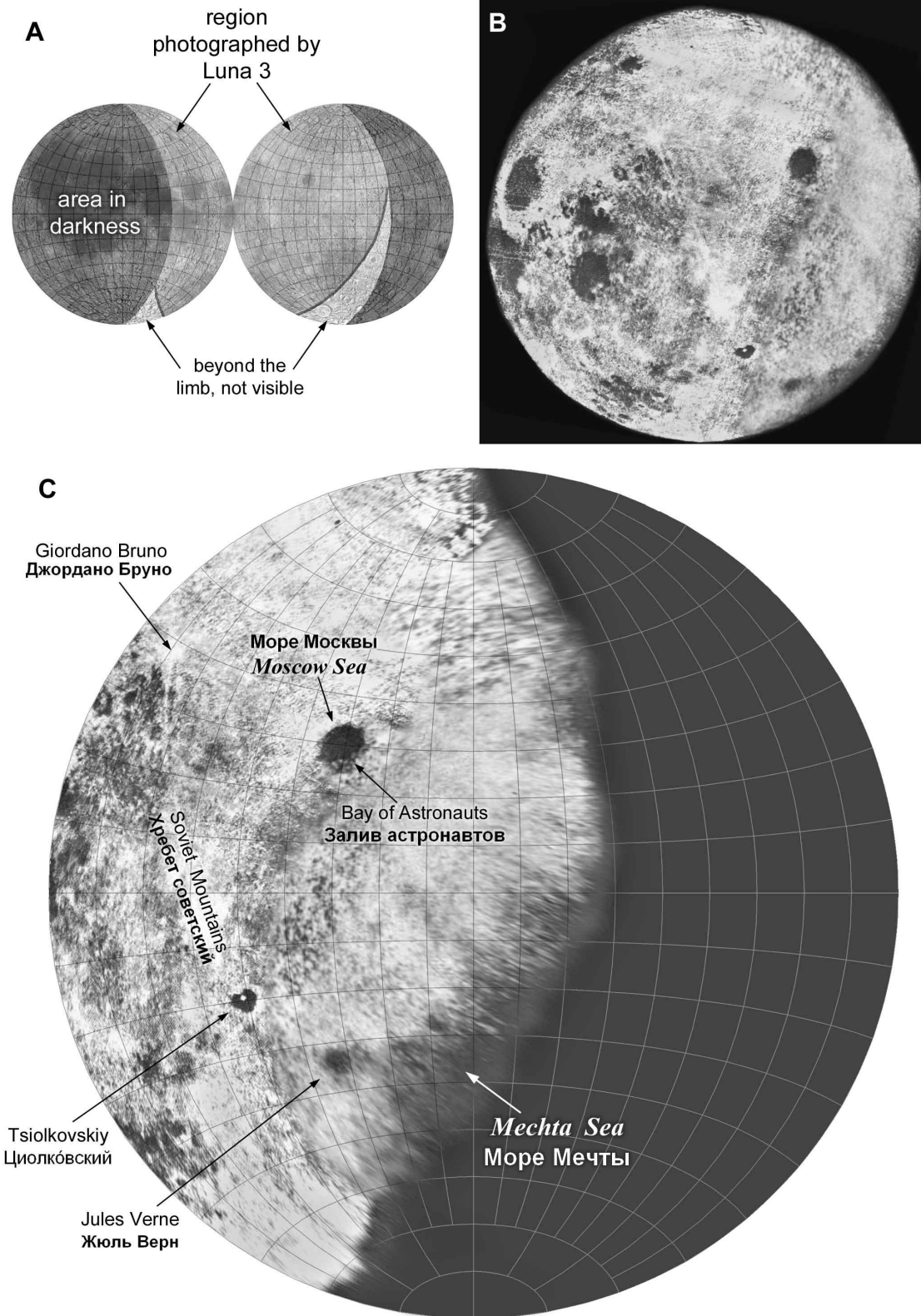


Figure 11. Luna 3 images. A: image coverage. B: composite of Luna 3 images. C: Farside photomap, with several names, also given in their Russian form. The gradual unveiling of the farside can be followed mission by mission in a sequence of maps. This map is followed by Figure 37C.

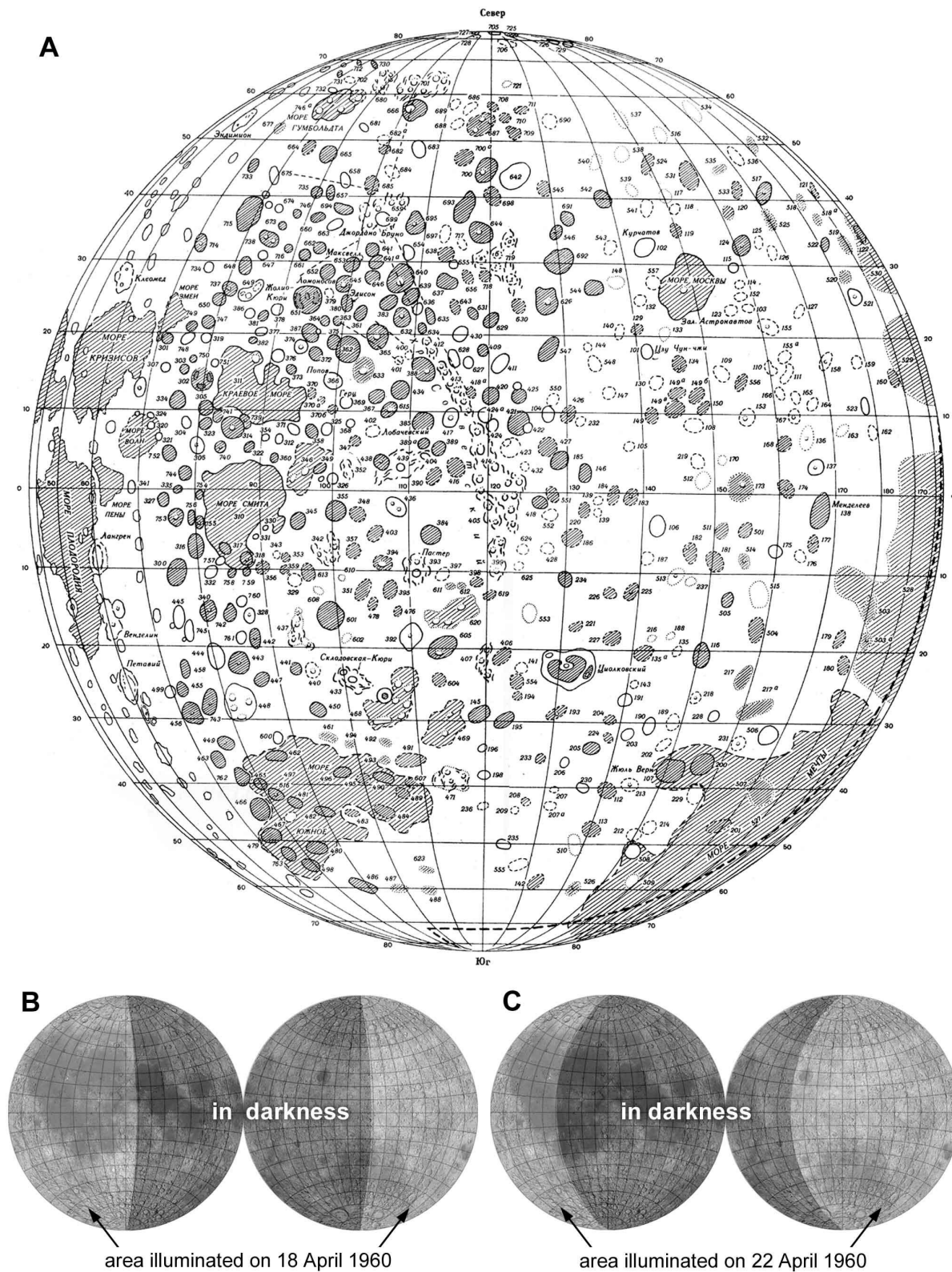


Figure 12. Early exploration of the lunar farside. A: First map of the region imaged by Luna 3 (Academy of Sciences of the USSR, 1960). B, C: areas illuminated during the planned imaging periods for Luna 1960A and 1960B, which would have completed the imaging of the farside if they had succeeded.

The Luna 3 images were timed to cover about two thirds of the farside and part of the Earthside, so that feature positions could be estimated. The lunar phase as seen from the spacecraft was nearly full, emphasizing albedo markings. About a third of the farside remained unseen (Figures 11, 12).

At this time the only farside map was that by Wilkins and Moore (Figure 5). Soviet scientists used it for comparison with the new images. One of the predicted ray craters was found to correspond to the new feature Giordano Bruno (Figure 11). Figure 11B is a composite by P. Stooke of images provided by V. Shevchenko. Figure 11C corresponds exactly to the geometry of Figure 2. The Figure 11B composite has been reprojected to fit that map. The progress of farside exploration can be followed through these chronicles as one mission after another adds details to the photomap.

Several features were given names. Most prominent is the dark-floored crater named after Konstantin Tsiolkovskiy, the Russian pioneer of cosmonautics. Astronaut Bay (Zaliv Astronavtov on Russian maps) was named before any astronaut had flown in space. The term 'cosmonaut' was not used in this case. The Montes Sovieticii (Soviet Mountains) were later found to be bright crater rays, not a mountain range, though the bright streaks are superimposed on an old basin rim. The Mechta Sea commemorates Luna 1, which was first named Mechta (Dream). The name is often translated misleadingly as 'Sea of Dreams'. It was later identified as the low albedo interior of the South Pole-Aitken basin (Chikmachev and Shevchenko, 1999). This name is still used today for Mare Ingenii on Russian maps. Figure 12 records the discoveries made in Luna 3 images and includes the first farside feature names.

Academy of Sciences of the USSR, 1960. *Atlas of the far side of the Moon*. Moscow: Akademiya Nauk.
Chikmachev, V. I. and Shevchenko, V. V., 1999. South Pole-Aitken basin on the first images of the lunar far-side. The international jubilee symposium "The scientific results of space research of the Moon". Sternberg State Astronomical Institute. Moscow: internet symposium, October 1999. <http://selena.sai.msu.ru/Symposium/South%20Pole.pdf>



26 November 1959: Pioneer P3

Pioneer P3, also called Able IV, was launched from the Atlantic Missile Range at 07:26 UT on an Atlas-Able booster. This intended lunar orbit mission disintegrated about 45 seconds after lift-off when the protective shroud covering the payload split open and broke up. The probe was sponsored by NASA, developed by the Jet Propulsion Laboratory, built by TRW and launched by the Air Force Ballistic Missile Division.

The spacecraft was initially designed for flight to Venus but was designated for a lunar mission after the Soviet success with Luna 1 in an attempt to be first in lunar orbit (Anonymous, 1959). It carried a scanning television camera, magnetometers and radiation detectors. The spacecraft was 1m in diameter, roughly spherical with four solar panels and weighed 169 kg. Circular heat-activated blades resembling propellers, distributed over the body, acted as a thermal control system. If it had succeeded in photographing the Moon from orbit, about three quarters of the far side could have been photographed at the time of arrival, very similar to the conditions for Pioneer 2 (Figure 8E).

Anonymous, 1959. 'Propellor blades' control Able IV heat. *Aviation Week*, v. 71, no, 10, 7 September 1959, p. 29.



1960: Khlebtsevich's Tankette

A Soviet concept for a tracked 500 kg rover for lunar exploration was considered at about this time. The vehicle, controlled from Earth, would carry a camera and a soil sample drill with analytical instruments. A searchlight would allow operations in shadowed areas or at night. The lunar poles were identified as interesting potential landing areas. The vehicle would have been powered by an internal combustion engine in this early design. The proposal was made by Yuri S. Khlebtsevich as early as 1954 but now seemed closer to reality than when first considered. The concept of automatically returning lunar soil to Earth was also mentioned in this report (Clark, 1960; Kreiger, 1958).

Clark, E., 1960. USSR Moon robot shot tests foreseen. *Aviation Week and Space Technology*, v. 72, no 3, 18 January 1960, pp. 28-29.

Kreiger, F. J., 1958. *Behind the Sputniks*. Washington, D.C.: Public Affairs Press.



1960: ABMA Lunar Program

The Jet Propulsion Laboratory in Pasadena, California and the Army Ballistic Missile Agency (ABMA) in Huntsville, Alabama (which launched JPL's Explorer 1, the first U.S. satellite, on 31 January 1958) devised a lunar exploration program at NASA's request. The Army had previous experience planning a lunar base (Project Horizon), and this remained their ultimate goal, but it would be attained via several intermediate steps.

First would be a series of four to six robotic circumlunar flights carrying cameras. Later flights would carry animals, and finally people by late 1966. Next, one or more landers and a series of rovers would explore the lunar surface. The conical lander ('stationary packet') would touch down protected by airbags, stabilized by eight projecting arms. The large (1000 kg) rover would consist of a payload package suspended from an axle linking two 5 m diameter tires. The vehicle would be driven by a small wheel on an arm trailing behind the main wheels. It would use solar heating to drive a liquid mercury turbine generator for electrical power, and would have had a minimum range of about 80 km over a full lunar day. Imaging during the final descent was considered to help plan safe routes. Both lander and rovers would carry television cameras and sample collection and analysis systems. ABMA planned two landers in 1965 and two rovers in late 1965 or early 1966. Human landings would follow.

ABMA suggested several possible landing sites (Table 2; Figure 13). Thermal control would be easier if landings took place at mid-latitudes. The first robotic lander would be sent to the early Ranger area in Oceanus Procellarum, near the craters Kepler and Lansberg, to take advantage of a vertical descent as planned for Rangers 3 and 4 (Figure 15C). Suitable rover targets would be areas containing several interesting features within driving range. Several of these sites were proposed by Clyde Tombaugh, discoverer of the planet Pluto, in an address to the American Rocket Society in March 1958. His preferred site, west of Aristoteles at 50.5° N, 11.0° E, was described at a colloquium held at JPL on 29 October 1958 (ABMA, 1960; Tombaugh, 1958).

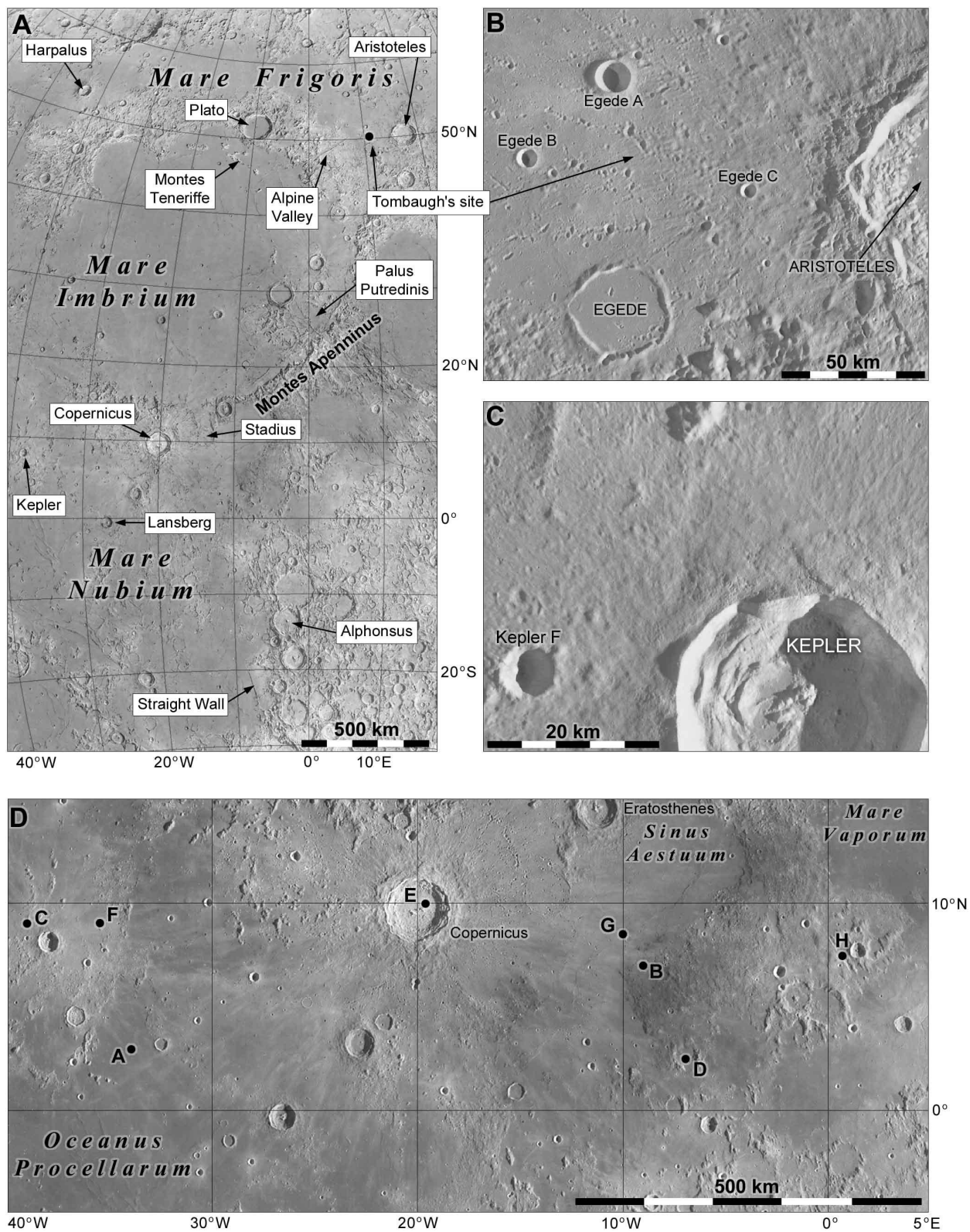


Figure 13. Early lunar probe landing site suggestions. A: ABMA rover landing sites (Table 2). B: Clyde Tombaugh's site near Aristoteles (Tombaugh, 1958). C: Green's Site C near Kepler. D: Jack Green's sites (Table 3). Images are LROC wide angle mosaics.

Table 2. ABMA Rover landing sites.

location	comments
Near Kepler	Early Ranger area (Figure 15C)
Stadius and Copernicus	Land in Stadius, explore the crater chains to the northeast, possible lunar base location (near the Project Horizon sites, Figure 9C).
Straight Wall	Land on lower side of the scarp, observe slope with cameras, take samples from foot of slope.
Alphonsus	Land on floor, use color TV to study central peak, dark spots and floor fractures. Carry instruments for volcanic gas analysis and mineralogical studies.
Mare Imbrium	Land in Palus Putredinis, drive from plains to nearby Apennine mountains. Similar sites are found on the northern edge of Mare Imbrium near the Teneriffe Mountains.
Plato	Land on lava-flooded floor, examine small post-mare craters.
Mare Frigoris	Land near Aristoteles, observe possible lava tubes.
Alpine Valley	Traverse length of valley, observe north and south walls, examine differences between them.
Harpalus	Site suggested for human exploration by Wernher von Braun (Table 1).

ABMA 1960. *A lunar exploration program based upon Saturn-boosted systems*. Development Operations Division, Army Ballistic Missile Agency, Report No. DV-TR-2-60, 1 February 1960.

Tombaugh, C., 1958. Where to Land on the Moon. *Proceedings of the Third Lunar and Planetary Exploration Colloquium*, v. 1, section 3, pp. 15-19. Downey, CA: North American Aviation Inc.



1960: Lunar probe landing sites

Jack Green of North American Aviation identified eight landing sites intended for small landing probes carrying seismic and thermal sensors (Table 3, Figure 13). This analysis (Green, 1960) assumed that the dark mare plains were basalt with very limited dust cover, and that craters like Copernicus and Kepler were volcanic in origin, an interpretation strongly disputed by Gene Shoemaker at the U.S. Geological Survey and many others (Wilhelms 1993), and he did not participate directly in Apollo mission planning. Crater rays would consist of debris thrown out of the craters whether they formed by impact or volcanism, though Green preferred the volcanic explanation, arguing that dust was carried aloft by carbon dioxide emissions during eruptions and that distant rays might be emitted from fractures radial to the crater rather than from the crater itself. Green also accepted the reality of Transient Lunar Phenomena (TLP), so some sites target these areas of supposed current activity. The seismic sensors would work better on the almost dust-free basalt surfaces and were not recommended for dusty crater rays.

Sites A and B on dark dust-free mare areas were considered the best locations. Sites F and G were on rays emanating from Kepler and Copernicus which might be studied further by exploding a charge to create a seismic signal near a geophone at F or G at a later date. Thermal conductivity would be measured as temperatures changed during a terminator passage. Area C was the site of a TLP observed in 1942 and the temperature probe might reveal a thermal anomaly. The ray cover made this site unsuitable for a seismometer. Area D in Schröter crater was the site of another reported TLP in 1903 and would also need a thermal instrument. Its rougher surface might require a more precise trajectory. Area H was near fractures (referred to as clefts) east of Ukert crater and would help resolve their formation mechanism, as long as the probe did not fall into a permanently shadowed crevasse. The northwest floor of Copernicus was of interest if the steep walls and central peaks could be avoided.

Table 3. Landing sites suggested by Green (1960)

Site	Description	Location	Site	Description	Location
A	Between Encke and Kunowsky	3° N, 34° W	E	NW* floor of Copernicus	10° N, 19.5° W
B	Northeast* of Schröter	7° N, 9° W	F	West* of Kepler	9° N, 35.5° W
C	East* of Kepler	9° N, 39° W	G	Rays west* of Copernicus	8.5° N, 10° W
D	Schröter	2.5° N, 7° W	H	Cleft east* of Ukert	7.5° N, 0.5° E

Order of priority for seismic studies: A, B, H, E, C, D, G, F
Order of priority for thermal studies: C, D, A, B, H, F, G, E

(*) Green's east and west terms are the old astronomical directions, the reverse of those used today. The current system came into use in 1960. The coordinates here are given in the current system, as in every other table.

Green, J., 1960. *Geophysics as Applied to Lunar Exploration. Final Report.* ARCRC Document no. AFCRL-TR-60-409, 30 June 1960. Bedford, Massachusetts: Air Force Cambridge Research Center.

Wilhelms D. E., 1993. *To a Rocky Moon: a geologist's history of lunar exploration.* Tucson: University of Arizona Press.



15 February 1960: Pioneer

A lunar spacecraft identical to Pioneers P-30 and P-31 was destroyed when its booster exploded during a static firing test. It was intended to enter lunar orbit carrying radiation sensors. It was not given a Pioneer number designation.



15 April 1960: Luna 1960A

This Luna spacecraft was similar to Luna 3. It was launched from Baikonur at 15:07 UT, but the third stage RO-5 engine failed to provide sufficient thrust and the spacecraft reached an altitude of 200 000 km before falling back to Earth. Its trajectory would have allowed it to photograph the part of the farside not observed by Luna 3, but with an improved camera and at closer range, giving higher resolution images.



19 April 1960: Luna 1960B

This Luna spacecraft was identical to the Luna launched only 4 days earlier. The launch date is sometimes given as 16 April. Its mission was also the same, to photograph the part of the farside not observed by Luna 3 at higher resolution than that spacecraft had achieved (Figure 25). After launch at 19:07 UT a strap-on booster failed to reach full thrust, and after less than a second of flight it broke away from the main rocket. The vehicle continued on its trajectory but without sufficient thrust to attain escape velocity.

The areas illuminated and able to be photographed by these two Luna missions are shown in Figure 12B and 12C. If either one had succeeded, most of the farside would then have been observed by the combined results of these missions and Luna 3.



23 June 1960: Soviet Lunar Flyby Project

A letter from Sergei P. Korolev to the Central Committee of the Communist Party in January 1960 outlined an extensive program of Soviet space developments. They would be made possible by the development of a new heavy launcher. Among these plans, in the period 1963 to 1965, were a spacecraft able to carry 2 or 3 men to the Moon, to orbit it and return to Earth. Korolev followed up on the letter by meeting with Soviet leader Nikita Khrushchev on 3 March 1960 to discuss this subject. However, the plans were not yet mature and had not been agreed among the Chief Designers of the various organisations involved. Khrushchev sent the matter back to the Designers for a consensus plan. Various projects were approved for further study or development in the Government decree 715-296 of 23 June 1960, 'On the Production of Various Launch Vehicles, Satellites, Spacecraft for the Military Space Forces in 1960-1967', including lunar soft landers and rovers, and cosmonaut landings. Although human visits to the Moon were being considered at this time, it was premature to consider specific landing sites.



25 September 1960: Pioneer P-30

This attempt to place a satellite in lunar orbit failed when the second stage of the launch vehicle failed to ignite. Launch was from the Atlantic Missile Range at 15:13 UT on an Atlas Able V booster. The spacecraft, known as Pioneer VI at the time, was identical to Pioneer P3 except that the television camera of the previous mission was replaced with radiation detectors to learn more about the structure of Earth's radiation belts and radiation in the vicinity of the Moon. Its mass was 176 Kg. The probe was sponsored by NASA, developed by the Jet Propulsion Laboratory, built by TRW, and launched by the Air Force Ballistic Missile Division. The lunar orbit would have been near-polar with a perilune (low point) of about 6000 km and apolune (high point) of about 9500 km.



15 December 1960: Pioneer P-31

The last Pioneer program attempt to place a satellite in lunar orbit failed when the Atlas-Able booster rocket went out of control and exploded 70 seconds after launch at a height of 12 km off Cape Canaveral. Launch was from the Atlantic Missile Range at 08:40 UT on an Atlas-Able IV booster. The spacecraft and mission plan were identical to Pioneer P-30. The probe was sponsored by NASA, developed by the Jet Propulsion Laboratory, built by Space Technology Laboratories (TRW), and launched by the Air Force Ballistic Missile Division.



20 April 1961: Prospector

Prospector was a proposed NASA/JPL unmanned lunar rover of the early 1960's (Anonymous, 1961). It would be able to soft-land 1100 kg of payload within one kilometer of a target anywhere on the nearside. A primary payload for Prospector would be a rover weighing 680 kg designed to undertake a detailed reconnaissance of the lunar surface throughout a radius of 80 km. It could also deposit landing aids or logistic material in support of a manned lunar landing. Walking, tracked and wheeled designs were considered, and a sample return version was contemplated. A seismometer could have been one of the instruments. On 20 April 1961 a conference was held at NASA Headquarters on the relationship between Prospector and Apollo. JPL representatives suggested modifying Prospector to offer more direct support to the manned lunar program. In the end, NASA needed precursor flights sooner than Prospector could be readied, and Surveyor evolved as a faster and cheaper alternative. In 1963 JPL briefly considered adding mini-rovers to Surveyor to recover some of the mobility of Prospector (Anonymous, 1963). Critics might have argued that Prospector could replace Apollo at much lower cost, a factor that may have hastened its demise.

General Electric described its version of a Prospector spacecraft (General Electric, c. 1961) which involved a lander, a rover and a sample return vehicle for pre-Apollo robotic missions. A landing site in the Straight Wall region was suggested because of the variety of materials found in the area. The three components for each mission would be launched together or on two launch vehicles, with sample return the main goal, as well as the delivery to Earth of a magnetic tape full of measurements of lunar data. Simple transmission of data was not thought sufficient.

Anonymous, 1961. JPL considers vehicle to return lunar sample to Earth for study. *Aviation Week and Space Technology*, v. 75, no. 5, 31 July 1961, pp. 58-60.

Anonymous, 1963. JPL outlines requirements for lightweight roving lunar vehicle. *Aviation Week and Space Technology*, v. 79, no. 1, 1 July 1963, p. 35.

General Electric, c. 1961. *Project Prospector. Unmanned Exploration and Apollo Support Program*. General Electric report, undated, no further identification.



25 May 1961: Kennedy's goal

In the context of the cold war and following Sputnik 1 (4 October 1957), the early Luna probes, and especially Yuri Gagarin's first human space flight in Vostok 1 (12 April 1961), U.S. President John F. Kennedy accepted the need to act boldly to regain the geopolitical and technological lead over the Soviet Union. In a speech to the U.S. Congress on this date he announced: "I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space, and none will be so difficult or expensive to accomplish." This did not mark the beginning of Apollo, which had been under consideration since 1959, but it did signal the transition from a mere concept to a funded program (Murray and Cox, 1989).

Murray, C.A. and Cox, C.B., 1989. *Apollo, the race to the Moon*. New York: Simon and Schuster.



26 May 1961: Lunex report

The day after Kennedy's speech the U. S. Air Force released a previously compiled report detailing its already well-developed plans for a lunar base. 'Lunex', the Lunar Expedition, had the objective of a first manned landing and return in late 1967, and a full-scale expedition to build a permanent base in 1968. A large three-stage booster would propel the Lunex spacecraft to the Moon. This would include a landing stage, a launching stage and the crew vehicle. Terminal guidance using pre-positioned beacons would be required for landing at a pre-selected site. The launching stage would propel the winged crew vehicle back to Earth where it would land on a runway like the later Shuttle. A cargo vehicle without a crew was also included in the Lunex plan. This would use the same booster and lunar landing techniques but would not return to Earth.

Before a landing site could be chosen, high resolution photographs of the lunar surface would be needed, and contemporary NASA plans for Ranger and Prospector or related spacecraft were expected to provide this information. Surveyor, then in the early planning stage, could have been modified to deploy radio beacons prior to the astronaut landings. This notion of pre-positioned beacons was a common feature of U. S. and Soviet plans at this time, though in the event they were not needed. Also, a drill-core sample of lunar material provided by an automatic lander was suggested as a helpful contribution to the design process for lunar landing systems and lunar facilities.

The Air Force's Lunex proposal and the U.S. Army's Project Horizon were soon abandoned in favour of the civilian lunar landing project, Apollo. The lack of a realistic military objective contributed to their demise (Miller, 1961; Stone, 1961). The Lunex report was available in January 2025 at the Encyclopedia Astronautica website (<http://www.astronautix.com/l/lunex.html>).

Miller, B., 1961. USAF sees need for 3-man lunar rover. *Aviation Week and Space Technology*, v. 75, no. 25, 18 December 1961, pp. 56-57.

Stone, I., 1961. USAF plans lunar shelter design study. *Aviation Week and Space Technology*, v. 75, no. 26, 25 December 1961, pp. 18-19.



June 1961: Early thoughts about landing sites

Following Kennedy's speech to Congress, cosmochemist Harold C. Urey, then at the University of California, was asked by NASA's Deputy Director of Space Flight Programs, Homer Newell, which areas he would like to see explored on the Moon. In a letter to Newell dated 19 June 1961 he recommended choosing sites which combined multiple scientific objectives, to minimize the number of required landings. He suggested five types of site: near-polar regions where the cold might allow ice to exist; the interior of a large crater; two different maria; one of the large 'wrinkle ridges' in the maria; and a mountainous region (Compton 1989, Chapter 3; Newell, 1973, pp. 1-5).

The first type of site could be near either pole (Figure 14), where Urey noted that Watson *et al.* (1961) had indicated that frozen water and other substances might survive in permanent shadows, contrary to previous analyses including one by Urey himself. Two large impact craters were also suggested as possible targets, Alphonsus and Copernicus. Alphonsus seemed old and had been the site of a spectroscopically observed gas emission (Figure 28). Copernicus seemed younger and was already being studied by Eugene Shoemaker, so it might be well enough understood to make a good target.

Table 4. Exploration scheme outlined by Green and Van Lopik (1961).

location	comments	location	comments
Agarum Prom.	view of Mare Crisium, reported mist	Liebnitz Mts	very high mountains, block faults?
Alpetragius	complex central mountain	Linne	reported changes
Alphonsus	central ridge, reported volcanic activity, dark vent deposits, base site?	Lyot (Ptolemaeus A)	very bright under high sun
Alpine Valley	craterlets; compare with rifts on Earth	Maclaurin	concave floor, part of crater chain
Altai Mountains	major scarp, regional viewpoint	Maclear	linear walls, dark floor, central peak
Archimedes	smooth floor material	Naumann	bright ejecta, radial dykes?
N of Aristarchus	reported colour changes	Newton	very deep, eternal shadow on floor
Aristillus	radially grooved ejecta	S of Nicolai	smooth light plains area
Atlas A	central peak, 'glitter' on crater floor	Nubium, Mare	centre of mare
Bartlett	reported changes in appearance	Petavius	complex central peaks
Bellot	smooth floor, high albedo	Philolaus	extensive terracing
Bessel	on ray crossing Mare Serenitatis	Picard	bright walls, largest crater in Crisium
Blancanus	bright walls, craters on rim	E of Pickering	traverse across unusual double ray
Brayley	radial dyke-like structures	Pico	crevasses, high albedo material
Bullialdus	terracing, internal ridge ring	Piton	summit pits, reported eruption clouds
Cassini	unusual central pit	Plato	smooth floor, reported changes
Cauchy	bright crater, reported changes	Proclus	rays, possible sulphur deposit, base site?
Censorinus	very high albedo crater, rays	Pytheas	unusually shaped crater
Cleomedes	N.E. part of floor; central peaks	Rheita Valley	crater chains on floor and flanks
Copernicus	central peaks, ejecta and rays, base site	Römer	central peak with summit pit
Crisium, Mare	central mare, deepest mare basin	Rothmann	ravine between wall and central peak
Dawes	radiating dyke-like structures	NW. of Sacrobosco	crater alignments
Eratosthenes	central peak with summit pit	Sasserides	crater chains radiating from Tycho
Firmicus	dark floor, low central peak	Schickard	mottled dark areas, light spots
Franklin	dark spots, possible changes reported	Schneckenberg	'spiral' hill north of Hyginus
Grimaldi	dark floor, greenish hue	Schröter	reported emissions, collapsed walls
Hainzel	intersecting craters	Serenitatis border	subsidence faults?
Hansteen	observed flash (impact?)	Serpentine Ridge	basaltic pressure ridge in Serenitatis
S of Harding	possible release of steam	Somnii, Palus	traverse from light to dark areas
Herodotus	white streak on floor	W of Stevinus	crater chains
Hevelius	fault and peaks on crater rim	Straight Wall	100 km fault scarp (Rupes Recta)
Hipparchus	large 'ruined' crater	Taruntius	dark inner ring on floor
Humboldtianum	centre of Mare Humboldtianum	Thales	reported 'mist', ray system
Hyginus	crater on complex fracture system	Theaetetus	reported 'steam' emission
Imbrium basin	supposed impact centre near S. Iridum	Theophilus	peaks with summit pits, base site?
Julius Caesar	central peak, summit pit, dark floor	Timocharis	ray system, central crater (vent?)
Kant	reported 'steam' emission	Tralles	central peaks cut by ravines
Kepler	rays and radial dyke-like structures	Tycho	terraces, rays, crater chains, base site?
E of Kies	dome with summit pit	NE of Ukert	radial structures centred on Imbrium
Lameche	split crater	Vogel	three 'fused' craters
SW of Langrenus	mountain with crater on summit	Wallace	lava-flooded crater
Prom. Laplace	viewpoint across Sinus Iridum	Wargentini	extreme case of crater infilling
Le Monnier	very level surface, base site?	Wöhler	smooth floor
Lichtenberg	rays, reported red glow	Zach	floor resembling crater lake
		Zupus	dark mottled floor, reported changes

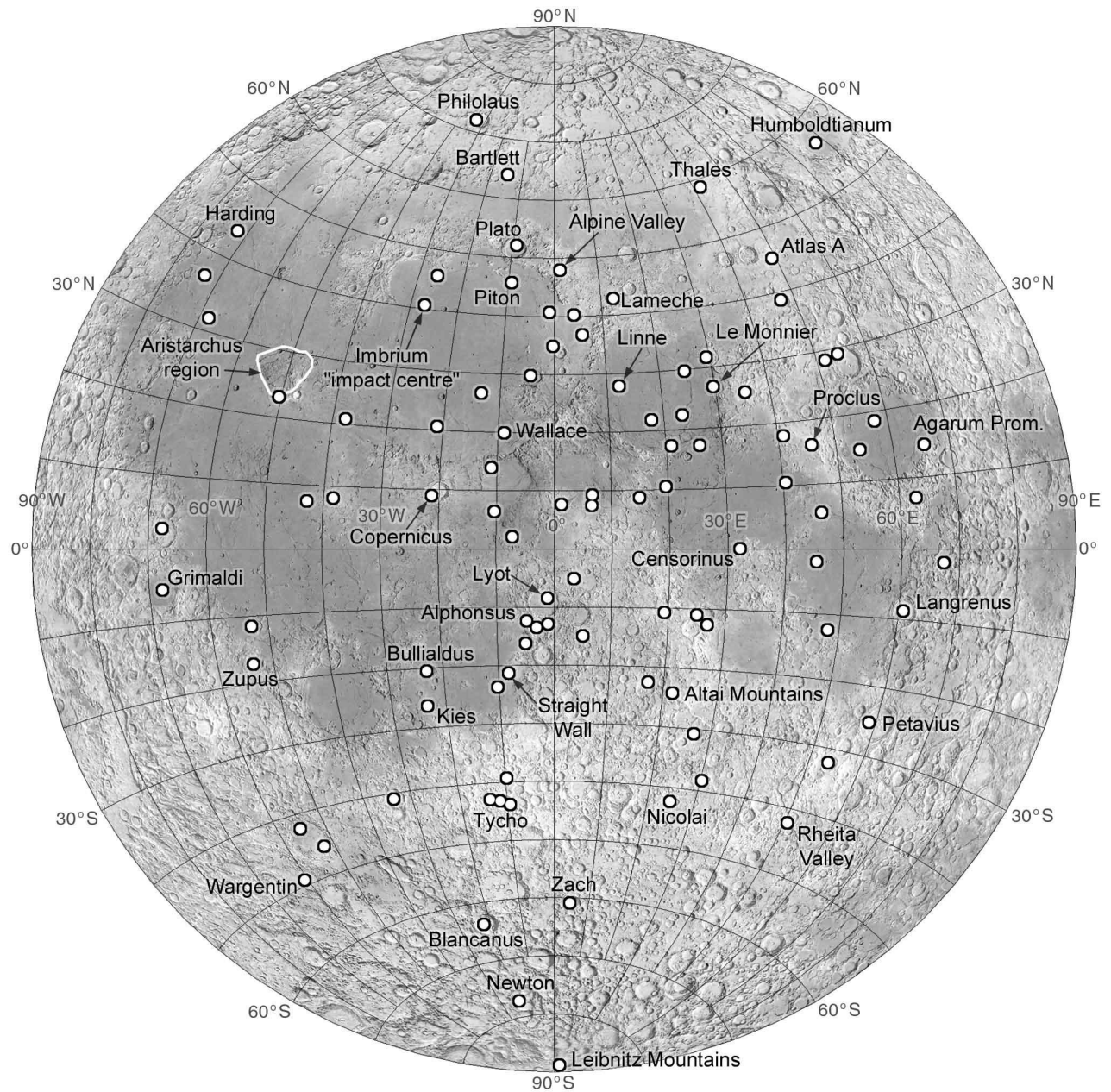


Figure 14: Exploration sites proposed by Green and Van Lopik (1961), from Table 4.

The two mare sites would explore distinctly different features. One would be a circular 'sea' occupying an impact basin, where a seismometer might reveal the depth excavated by the impact before the deep hole was filled with impact melt or lava. A favoured candidate was Mare Imbrium, whose somewhat asymmetric structure had been interpreted as due to an oblique impact. The impactor was thought to have excavated Sinus Iridum before penetrating more deeply to the southeast and exploding to create the main basin. A more recent interpretation would view Sinus Iridum as a large crater superimposed on the older basin rim. In Urey's view the dark plain resulted from rock melted by the impact, not a later volcanic event. The other mare site would be on either Oceanus Procellarum or Mare Tranquillitatis, which had irregular shapes and many hills and crater rims protruding through the shallow lava. Oceanus Procellarum was preferred because of its vast expanse and few obstacles.

Urey thought that the prominent 'wrinkle ridges' in the maria might be places where water had risen to the surface and dissipated, possibly leaving salt deposits forming bright spots sometimes exposed on their crests. Ridges in Mare Imbrium near Sinus Iridum would be good targets since they would also allow study of the Imbrium impact area. Small dome-like hills resembling volcanoes near Hortensius crater and Copernicus might also be related to the ridges and could be explored along with Copernicus itself.

The mountainous area Urey suggested was Montes Haemus which formed the southern rim of the Serenitatis basin. Urey described the mountains as ridges of ejecta thrown out of the Imbrium basin as it formed, not Serenitatis rim material sculpted and blanketed by Imbrium ejecta as they would be interpreted later by Shoemaker and his colleagues. In addition to these areas, Urey described a few other areas of interest, a dark linear marking in Mare Serenitatis which he thought might consist of carbon, the complex area around Aristarchus and Herodotus which was frequently associated with reports of TLPs, and Lacus Mortis which appeared to be a fault-bounded depression.

Polar ice has always been attractive to mission planners, but it is interesting with a 21st Century perspective to note omissions from Urey's list. The Orientale basin, which now seems so prominent, had not yet been identified. The Marius Hills and other locations evocative of volcanic activity were overlooked, and sinuous valleys such as Rima Hadley and crater rays like those around Kepler, Copernicus and Aristarchus were ignored. Perhaps most importantly, there was no suggestion that material of different ages might be sampled to help define the chronology of lunar geological evolution. Urey believed that the Moon was primitive and undifferentiated, and therefore had no significant geological history to decipher. The geological emphasis was only just emerging as a result of work by the pioneering lunar researcher Eugene Shoemaker and colleagues at the U.S. Geological Survey.

Despite the new ideas being espoused by geologists, Shoemaker (1962) took a completely different approach to planning, pointing out that operational constraints would outweigh purely scientific preferences. He foresaw a sequence beginning with several Ranger missions photographing the Moon from close range before striking the surface. The first Surveyor soft lander would touch down at one of those Ranger sites, while orbiters searched for suitable Apollo landing sites. Then most of the remaining Surveyors would be sent to inspect the candidate Apollo sites, with one or two others perhaps going to particularly interesting non-Apollo sites.

Jack Green had suggested eight sites for robotic probe landings in 1960 (Figure 13), and a year later he and Jack Van Lopik expounded their ideas for lunar exploration in greater detail, reflecting their volcanic interpretation of surface features (Green and Van Lopik, 1961). His scheme is summarized in Table 4 and Figure 14. At about this time a study by DeNike and Zahn (1962) recommended a flat area of Mare Tranquillitatis for a lunar base and suggested that it might be buried or constructed in an underground cavity to protect against micrometeorite impact and radiation.

Compton, W. D., 1989. *Where no man has gone before: a history of Apollo lunar exploration missions*. NASA SP-4214. Washington, D.C.: National Aeronautics and Space Administration.

DeNike, J. and Zahn, S., 1962. Lunar Basing. *Aerospace Engineering*, v. 21, pp. 8-14.

Green, J. and Van Lopik, J. R., 1961. The role of geology in lunar exploration. *Advances in Space Science and Technology*, v. 3, 1961, pp. 1-112.

Newell, H. E., 1973. Harold Urey and the Moon. *The Moon*, v. 7, nos. 1/2, March-April, 1973, pp. 1-5.

Shoemaker, E. M., 1962. Exploration of the Moon's surface. *American Scientist*, v. 50, pp.99-130.

Watson, K., Murray, B. and Brown, H., 1961. On the possible presence of ice on the Moon. *Journal of Geophysical Research*, v. 66, no. 5, pp.1598-1600. <https://doi.org/10.1029/JZ066i005p01598>



26 January 1962: Ranger 3

Rangers 1 and 2 were engineering tests intended to operate in high Earth orbit. On 23 August 1961 Ranger 1 was launched from the Atlantic Missile Range on an Atlas-Agena B booster, but its Agena upper stage failed to burn to raise the orbit, stranding Ranger 1 in a lower orbit than intended. It re-entered on August 29 after 111 orbits. On 18 November 1961 Ranger 2 was stranded in a parking orbit after a failed gyro prevented the upper stage burn intended to place it on a higher orbit as a systems test.

Ranger 3 was the first of the series to be targeted at the Moon. The 330 kg sterilized spacecraft had a 1.5 m diameter hexagonal base supporting two solar panels with a total span of 5.2 m, and carried a camera for imaging during descent to the Moon, a gamma-ray spectrometer on a 1.8 m arm, a radar altimeter, and a seismometer floating in oil in a 27.5 cm diameter spherical capsule encased in a 67 cm balsawood shock-absorbing sphere.

The lunar capsule would be ejected at an altitude of about 24 km above the lunar surface, and slowed by a small retrorocket to reduce its velocity to zero at a height of 350 m. At that altitude the landing capsule would be ejected. It was designed to survive impact on the Moon at up to 160 km/hr, using batteries to operate its seismometer and radio equipment for 30 days. The radar altimeter would measure the height of the spacecraft above the Moon and was also intended for reflectivity studies. The 200 scan line images would be taken at 10 second intervals, interspersed with gamma ray spectrometer data on lunar surface composition. The first image was to be taken from 300 km to show an area 2° (60 km) across. The last would cover an area 2 km across at a resolution of 10 m per pixel.

After launch at 20:30 UT from the Atlantic Missile Range, a booster guidance error caused excessive speed which could not be fully corrected by the mid-course correction system. An attempted correction with erroneous coordinates resulted in a change in the opposite direction. Ranger 3 was intended to impact on the Moon (Figures 15B, 15C), but missed by 36,800 km on 28 January and entered a solar orbit with a period of roughly 400 days. The spacecraft was oriented for photography during the flyby in the hope that it would reveal part of the far side not seen by Luna 3 (Figure 15A), but it began to tumble, losing reliable camera pointing and communication. Several pictures were obtained but did not show the Moon. Some cosmic gamma-ray measurements were partially completed. Attempts to bounce radar signals off the Moon were unsuccessful. Burke (1963) says Ranger 3 was tracked out to about 0.7 million km on 31 January 1962 and may have locked onto the Moon and stopped rotating after the picture-taking sequence.

Burke, J., 1963. Ranger Project Status. In *Technology of Lunar Exploration* (Cummings, C. I. and Lawrence, H. R., eds), *Progress in Astronautics and Aeronautics*, v. 10, pp. 855-876. New York: Academic Press.



23 April 1962: Ranger 4

Ranger 4's spacecraft and mission were identical to Ranger 3. It was intended to transmit pictures of the lunar surface in the last 10 minutes before striking the Moon, to land a seismometer capsule on the Moon, to make gamma-ray studies, to measure the Moon's radar reflectivity and to build engineering experience for lunar and interplanetary flights. This section includes material from NAS-NRC (1962) and Adamski (1962).

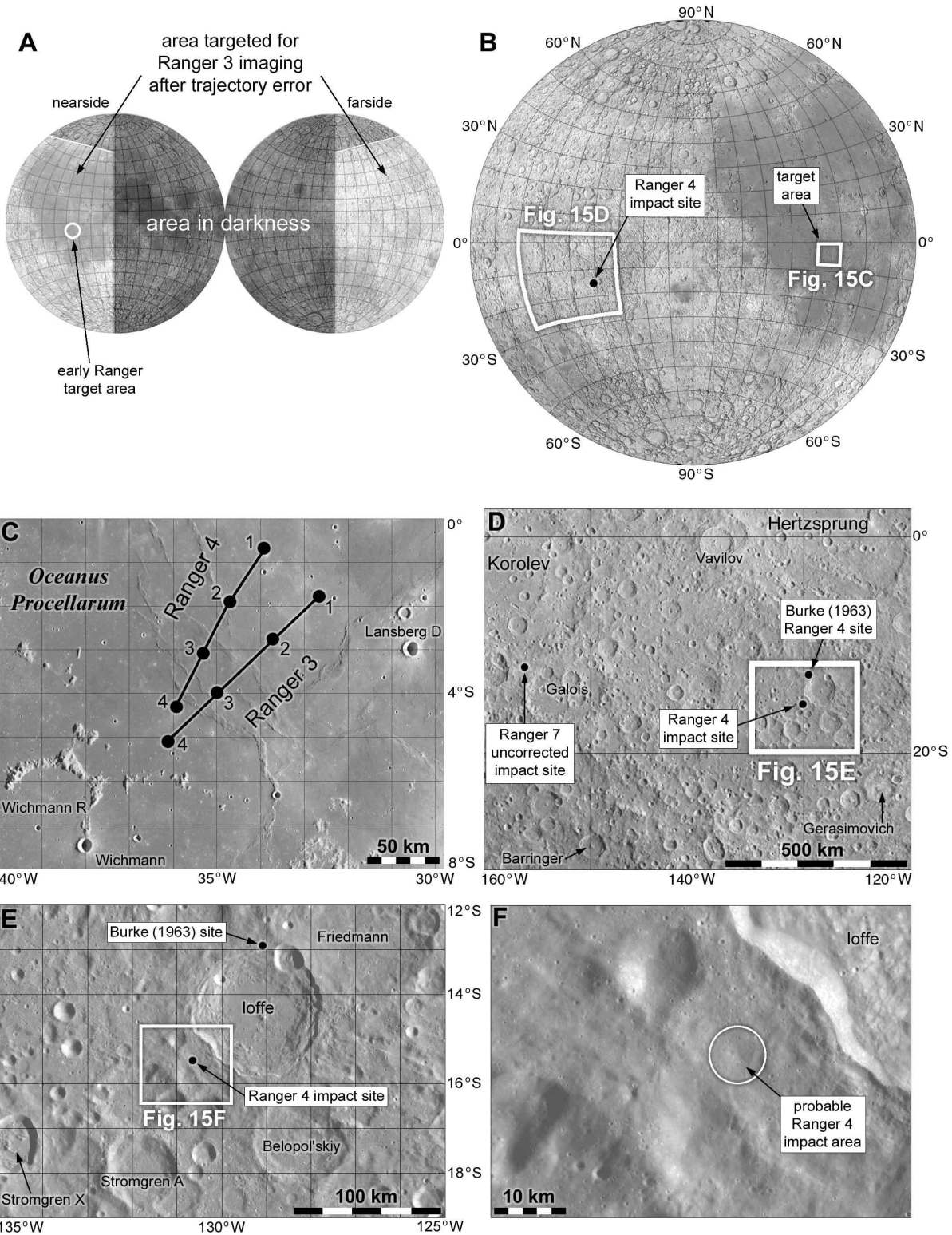


Figure 15. Ranger 3 and 4 missions. A: Ranger 3 target area and potential image coverage. B: Ranger 4 target and impact sites. C: Ranger 3 and 4 nominal landing points for successive days in the four day launch period. D: Ranger 4 impact region, with the uncorrected impact point for Ranger 7 (if no trajectory correction had occurred). E, F: The Ranger 4 impact site. Base images are LROC wide angle mosaics.

It was launched at 20:50 UT on 23 April 1962 from the Atlantic Missile Range on an Atlas-Agena B booster, entered a parking orbit, and was placed on its lunar trajectory by a second burn of the upper stage. The failure of a timer in the spacecraft caused loss of both internal and ground control over the vehicle, so no photographs or other data were obtained. Transmissions from the battery-powered transmitter in the landing capsule were tracked until Ranger 4 passed behind the western limb of the Moon on 26 April 1962. It crashed on the farside with a speed of 9617 km per hour at 12:49 UT after 64 hours of flight, becoming the first American spacecraft to reach the lunar surface. The Agena upper stage missed the Moon and entered a solar orbit.

Rangers 3 and 4 were both aimed at a small area just south of the equator in Oceanus Procellarum, which was dictated by the trajectory design and the desire for a vertical descent to the surface (Figure 15B, 15C). A vertical descent would allow the images to ‘nest’ properly, each within the area of the previous image, to help locate the landing site precisely. Although there would be some scientific value in the images, their main function was to locate the landing site. U.S. Army and Air Force cartographers each prepared experimental maps of the area at 1:250,000 scale in preparation for the missions. In Figure 15C, two lines show how the ‘nominal landing point’, the predicted vertical descent point, moved across the surface for different launch dates in the planned four day launch periods for Rangers 3 and 4. Launch was restricted to a few days each month when lighting would be acceptable for photography in the desired target region.

Ranger 4 crashed on the farside at about 15.5° S, 130.7° W (Roncoli, 2005), about 300 km south of the rim of the giant Hertzprung basin. Burke (1963) gives the position as 12.9° S, 129.1° W, ----- states 12.0° S, 128.6° W and Renzetti (1964) gives it as 15.5° S, 130.5° W. Burke’s position is probably a preliminary result and less accurate than the later values. Figure 15D shows the rugged cratered terrain in this region, which includes some of the highest elevations on the lunar surface. Figure 15E and 15F show the impact area itself, just southwest of the 80 km diameter crater Ioffe. It is not possible to associate any specific small crater with the impact.

Adamski, D. F., 1962. *The lunar seismograph experiment: Rangers 3, 4, 5*. JPL Technical Report 32-272, 1 June 1962.

Burke, J., 1963. Ranger Project Status. In *Technology of Lunar Exploration* (Cummings, C. I. and Lawrence, H. R., eds), *Progress in Astronautics and Aeronautics*, v. 10, pp. 855-876. New York: Academic Press.

Hamilton, T. W., Sjogren, W. L., Kirhofer, W. E., *et al.*, 1962. The Ranger 4 flight path and its determination from tracking data. JPL TR-32-34515 September 1962.

NAS-NRC, 1962. A review of space research, report of the summer study conducted under the auspices of the Space Science Board at the State University of Iowa, June 17-Aug. 10, 1962, National Academy of Sciences-National Research Council Publication 1079 (Washington, 1962).

Renzetti, N. A., 1964. *Tracking and data acquisition for Ranger missions 1 - 5*. NASA-CR-58537, report no. JPL-TM-33-174. Pasadena: Jet Propulsion Laboratory, 1 July 1964.

Roncoli, R., 2005. Lunar Constants and Models Document. Jet Propulsion Laboratory Technical Document D-32296, 23 September 2005. https://ssd.jpl.nasa.gov/doc/lunar_cmd_2005_jpl_d32296.pdf



16 May 1962: Soviet N1 Lunar Project

A draft project for human lunar exploration was completed by Korolev’s team on 16 May 1962. The design was defended before the other Chief Designers from 2 to 16 July 1962. The large three stage N-I booster would be used, with the following lunar objectives:

- (1) Circumnavigation of the Moon with a crew of two to three people, and lunar orbit operations by people and automated vehicles for scientific study of the lunar surface;
- (2) Lunar landings for geological studies and the selection of a suitable site for a scientific base on the Moon;
- (3) Establishment of the lunar base and regular travel between Earth and the Moon.



July 1962: Surveyor Lunar Orbiter

High resolution imaging of potential landing sites would soon be needed for Apollo site selection and mission planning. The Ranger program would provide high resolution images only for very small areas and was not an efficient method to certify a large number of sites. The Jet Propulsion Laboratory was developing a lunar landing vehicle to be called Surveyor, and now began to consider it for an orbital mission with cameras in place of its surface experiments and descent systems.

An original plan envisioned photographing the whole surface at visible and thermal infrared wavelengths from a polar orbit, with emphasis on the far side. Global resolution would be 100 m, with spot coverage at 10 m or better. As the needs of Apollo grew this plan was modified to photograph the area between 20° North and South of the equator and between 50° East and West (Figure 16A). This is somewhat larger than the Apollo landing zone as later defined.

All early impact and landing studies noted that a simple vertical descent could be achieved readily from likely approach trajectories in the western half of the nearside, so that region was preferred for the early Ranger, Surveyor and Luna missions. Conversely, return was easier from the eastern half of the nearside. Either area would be suitable for Apollo, but the west was favoured because Ranger and Surveyor data would be easier to obtain for planning purposes. The larger latitude extent reflected the possibility of mission architectures involving direct flights from Earth orbit to the lunar surface without a lunar orbit phase. When lunar orbit rendezvous was selected for Apollo in 1962, early near-equatorial landings were mandated. The area considered for landings at that time (Sullivan, 1962, page 90) extended from about 0° to 70° W and 10° N to 10° S (Figure 16A).

Six Surveyor Orbiters would be built, of which five would fly with one as a spare. The spacecraft had Surveyor's triangular frame, without landing legs but with two large solar panels similar to Ranger's. The flights would occur in the 1964 to 1965 period, with spacecraft operating from a 100 km orbit. Images would have a resolution of 100 m over most of the area, with 10 m resolution over specific sites of interest and stereoscopic imaging capability for accurate topographic mapping. Apollo planners soon demanded wider coverage at still higher resolution, and it became apparent that the Surveyor Orbiter could not produce the necessary data. The mission was eventually replaced by the much more capable Lunar Orbiter spacecraft (Miller, 1962; NAS-NRC, 1962).

Miller, B., 1962. Lunar orbit photo mission wins approval. *Aviation Week and Space Technology*, v. 77, no. 4, 23 July 1962, pp. 22-23.

NAS-NRC, 1962. *A review of space research*, report of the summer study conducted under the auspices of the Space Science Board at the State University of Iowa, June 17-Aug. 10, 1962, National Academy of Sciences-National Research Council Publication 1079 (Washington, 1962).

Sullivan, W. (ed.), 1962. *America's race for the Moon*. New York: Random House.



18 October 1962: Ranger 5

The Ranger 5 spacecraft and mission plan were identical to Rangers 3 and 4. Ranger 5 was launched at 16:59 UT from the Atlantic Missile Range on an Atlas-Agena B. The vehicle entered its parking orbit and after 25 minutes the booster re-ignited to place Ranger 5 on a lunar trajectory. A guidance system malfunction caused excessive velocity and an unknown failure caused a loss of power, but the spacecraft was tracked for 8 hours, 44 minutes, before its battery died. Problems similar to those of Ranger 3 prevented television imaging, but cosmic gamma-ray data were collected for 4 hours prior to battery failure. Ranger 5 missed the Moon by 725 km and entered solar orbit.

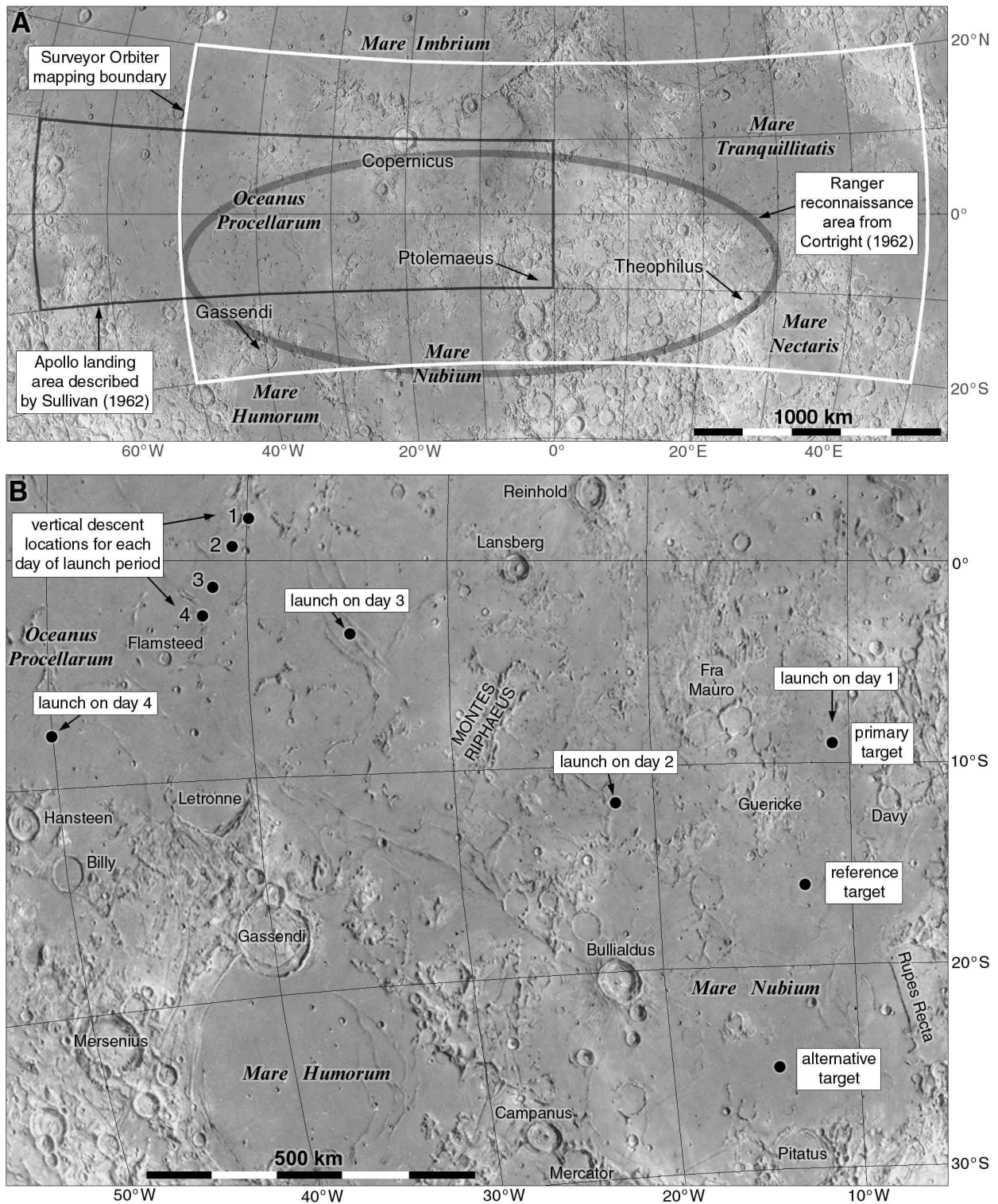


Figure 16: Surveyor Orbiter and Ranger 5 planning. A: Ranger reconnaissance area, Surveyor Orbiter image coverage goal and Apollo planning area, 1962. B: Ranger 5 targets and vertical descent locations (Kirhofer, 1962) from Table 5.

Ranger 5 targets were more dispersed than those for Rangers 3 and 4 (Kirhofer, 1962). The earlier trajectories were intended to fall nearly vertically to ensure nested imaging during the descent, but lighting changed so much from day to day that it might only be optimal at the target on one day of the four day launch period. Accordingly, for Ranger 5 different targets were chosen for each day, each about 30° west of the terminator at the time of impact (Table 5, Figure 16B). The day 3 target is essentially the same as the day 3 targets for Rangers 3 and 4. On the first day two sites were chosen, a primary and an alternative target. The reference trajectory was designed to impact between them, and the actual target would be reached by making a trajectory correction to the north or south. In May 1962, when Ranger 5 was still targeted at the vertical impact region, Cortright (1962) illustrated that area and the larger ellipse accessible for later Ranger reconnaissance missions (Figure 16). He suggested that Ranger 5 could carry two small explosive charges to ensure that the seismometer would detect a signal, though this was not attempted.

Table 5. Ranger 5 targets from Kirhofer (1962)			
Launch date*	Target location	Vertical impact**	Notes
1	16° S, 12.5° W	2° N, 40° W	Reference trajectory target, Mare Nubium near Opelt
1	9° S, 11° W		Primary target, Mare Nubium near Guericke
1	25° S, 14° W		Alternative target, Mare Nubium near Wolf
2	12° S, 22° W	0.5° N, 40.5° W	Mare Cognitum near Darney (south of Ranger 7)
3	4° S, 35° W	1.5° S, 41.5° W	Oceanus Procellarum near Wichmann
4	8° S, 50° W	2.5° S, 42° W	Oceanus Procellarum near Hansteen
* Launch dates denote the day of the four day launch period			
** Location of the vertical impact point for that date			

Cortright, E. M., 1962. Space Science: Moon and Planets. *Proceedings of the Second National Conference on the Peaceful Uses of Space, Seattle, Washington: 8 to 10 May 1962*. NASA SP-8, pp. 49-58. Washington, D.C.: National Aeronautics and Space Administration.

Kirhofer, W. E., 1962. *Post Injection Standard Trajectory, Ranger P-36 (RA-5)*, Volume 1. Engineering Planning Document no. 105. Pasadena: Jet Propulsion Laboratory, 21 September 1962.



04 January 1963: Luna 1963A (Sputnik 25)

This mission was the first flight for a new series of lunar spacecraft which eventually triumphed with the successful landing of Luna 9 (Figure 41). Its goal was an attempted lunar soft landing near the equator in western Oceanus Procellarum, with the intention of returning images and data on the mechanical and radiation characteristics of the lunar surface in preparation for possible future human landing missions. The 3 m high, 1500 kg spacecraft consisted of a cylindrical section containing landing rockets and fuel, side-mounted attitude control systems and sensors and a spherical top section containing the 100 kg lander. The side-mounted units were to be discarded to save braking fuel as the vehicle prepared for its final descent and would fall in the vicinity of the landing site. The lander would be ejected onto the surface as the main body touched down, carrying a camera and devices to measure radiation.

The spacecraft was launched into an Earth parking orbit at 07:12 UT by the SL-6/A-2-e launcher but failed to enter a lunar trajectory. The payload escape stage failed to separate due to a power system failure. The stage with payload remained in Earth orbit until it re-entered on 5 January 1963 after one day. In accordance with Soviet practice the lunar identification was not announced at the time. Sputnik 25 was originally designated Sputnik 33 by the U.S. Naval Space Command.



1963: Sonett Report

NASA's Office of Space Science (OSS) appointed a group headed by physicist Charles Sonett of the University of Arizona and including Gene Shoemaker, Gerard Kuiper, Thomas Gold and Harold Urey to develop scientific proposals for Apollo. Their draft report (Sonett, 1963), informally called the Sonett Report, was prepared in July 1962 and formally distributed late in 1963. This was the first official document to call for extensive lunar scientific exploration rather than the single landing mandated by President Kennedy.

The group proposed that landing sites should be photographed by robotic orbiters. Planning field work in advance would save time during surface activities. They indicated a need for a rover with a range of tens of kilometers, the automated landing of supplies before astronauts arrived, a geophysical experiment package to be left on the Moon, and surface stay times of up to 120 hours on later missions. A particular emphasis was placed on the need for landings outside the narrow equatorial zone. The report included two sets of proposed sites (Table 6, Figure 17), one compiled by Gene Shoemaker and Dick Eggleton (USGS), the other by Duane Dugan (NASA Ames Research Center). Dugan's Aristarchus and Theophilus positions were intended to sample ejecta rather than the crater itself. The final report recommended that the first landing take place at 3° N, 28° W, near the early Ranger target area southwest of Copernicus (Figure 17), and that orbital photography would be needed to certify other sites (Sonett, 1963).

The Flamsteed and 'SE of Copernicus' sites were also suggested in Apollo Working Paper 1100 (Table 7), and the sites at Aristarchus, Tobias Mayer, Copernicus, Gassendi and Alphonsus were considered later by the Apollo Site Selection Board.

In a meeting at about this time, participants were asked if they would travel to the Moon even if it was certain they could never return. Only Urey and Shoemaker said they would undertake the one-way trip, according to an anecdote originally told by Urey to Jafar Arkani-Hamed (and by Arkani-Hamed to the author).

Table 6. Landing sites proposed in the Sonett Report

Shoemaker and Eggleton (USGS)			Dugan (NASA Ames)		
Site	Location	Description	Site	Location	Description
SE of Hortensius	5.6° N, 26.6° W	Rimless pit	SE of Copernicus	5° 50' N, 14° 30' W	Dark mare, dome
Copernicus floor	9.8° N, 20.1° W	Near central peaks	Riphaeus Mts	5° 00' S, 28° 10' W	Old craters, mare
SE of Copernicus	5.1° N, 14.2° W	Dark mare material	Flamsteed ring	3° 00' S, 44° 00' W	Ghost crater, mare
Floor of Hyginus	7.7° N, 6.3° E	Volcanic crater	Ptolemaeus floor	9° 00' S, 2° 00' W	Crater plains fill
Rim of Parry A	9.1° S, 16.1° W	Unusual ejecta	Alphonsus floor	13° 00' S, 2° 30' W	Vents, fractures
T. Mayer dome	13.1° N, 31.0° W	Volcanic dome	Aristarchus	23° 40' N, 43° 30' W	Fresh ray crater
Alphonsus floor	12.6° S, 2.0° W	Volcanic features	Herodotus floor	23° 00' N, 51° 45' W	Crater, venting?
Mt. Huygens	20.4° N, 3.0° W	Apennines, mare	Mt. Huygens	20° 30' N, 3° 40' W	Apennines, mare
Rümker hills	41.7° N, 57.5° W	Volcanic hills	Linne crater	28° 00' N, 12° 00' E	Reported activity?
Tycho crater rim	40.9° S, 11.1° W	Highland ray crater	Plinius crater	15° 00' N, 22° 00' E	Crater, dome, mare
Mare Imbrium	37.9° N, 16.4° W	Lava flow features	Gassendi crater	19° 30' S, 40° 20' W	Fractures, peak
N of crater Billy	12.7° S, 49.8° W	Bright plateau	Mare Humorum	24° 30' S, 43° 40' W	Mare, faults
Spitzbergen Mts	35.3° N, 5.5° W	Mare, ridge, hills	Theophilus	4° 50' S, 25° 50' E	Mare, crater
Wargentín crater	50.6° S, 60.8° W	Filled crater			
Amundsen floor	85° S, 45° E	Ice in shaded area			

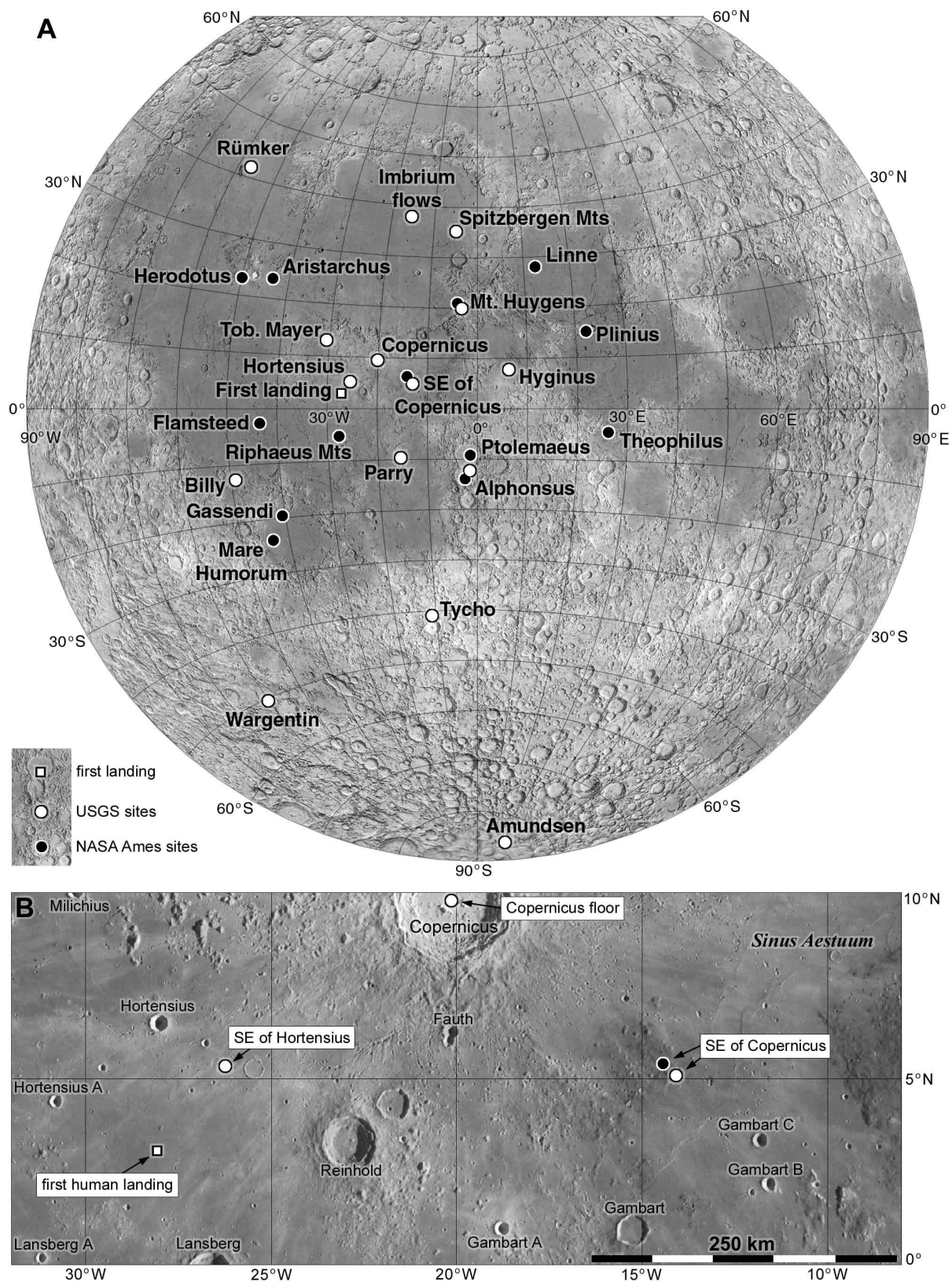


Figure 17: Landing sites suggested in the Sonett Report, from Table 6. A: all sites. B: sites near Copernicus.

Sonett, C. P., 1963. *Report of the ad hoc working group on Apollo experiments and training on the scientific aspects of the Apollo program*. Washington, D. C.: NASA, 15 December 1963.



03 February 1963: Luna 1963B

This spacecraft is believed to have been another attempted lunar lander, targeted for the same region of Oceanus Procellarum as Luna 1963A (Figure 34). It was launched from Baikonur, but 105 seconds after launch the gyro of the onboard trajectory tracking system began to deviate from the expected values. Attitude control was lost at 295 seconds, following second stage separation. The upper stages and payload broke up on re-entry into the atmosphere over the Pacific Ocean.



02 April 1963: Luna 4

The 1422 kg Luna 4 is believed to have been another attempted lunar lander, as were its two predecessors and the future Lunas 5 to 9. Luna 4 was launched from Baikonur at 08:04 UT. The spacecraft, rather than being sent directly toward the Moon as Lunas 1 and 2 had been, was placed in an Earth parking orbit from which it was propelled towards the Moon by a later burn of its Molniya booster upper stage. Luna 4 achieved nearly the desired trajectory but failed to make a necessary midcourse correction and missed the Moon by 8336 km at 13:25 UT on 5 April 1963. A program called "Hitting the Moon" was scheduled to be broadcast on Radio Moscow at 7:45 p.m. on the evening of 5 April but was cancelled.

Luna 4 entered a 90000 by 700000 km Earth orbit and was later perturbed into a solar orbit. The spacecraft transmitted at 183.6 MHz at least until 6 April, and Lyubimov (1967) states that some radiation measurements were obtained from Luna 4. Its close pass by the Moon resulted in its official 'Luna' designation. Unconfirmed reports from Italian sources on 8 April that images were received from Luna 4 (Kolcum, 1963) are erroneous, probably referring to non-imaging transmissions and suggestions that the lander carried a camera.

The Molniya upper stage also entered a heliocentric orbit. On 16 May 2010 an object initially referred to as RK252A5 was detected by the Catalina Sky Survey. It was assumed to be a small asteroid and was renamed 2010KQ, but its orbit was modified by solar radiation pressure to such an extent that it could only have been an artificial object. Its reflection spectrum suggested a painted surface, and it may have been the Molniya upper stage of Luna 4.

The early Luna landers were targeted for a broad region near the equator in western Oceanus Procellarum (Figure 38B) dictated by the Luna trajectory design. A different flight profile produced a somewhat different vertical descent point for the Lunas than for the early Rangers (Figures 15C, 16B). Specific target points for individual missions were chosen on the basis of albedo (K. Shingareva, personal communication, June 2001). Dark areas were expected to be smoother on the assumption that crater rays represented areas disrupted by debris thrown out of craters, so areas without bright rays should be safer for landing. This assumption also guided Ranger, Surveyor and early Apollo site planning.

Kolcum, E. H., 1963. Lunik 4 believed to have failed in mission. *Aviation Week and Space Technology*, v. 78 no. 15, 15 April 1963, p. 38.

Lyubimov, G.P., 1967. Measurement of the Intensity of Cosmic Radiation During the Flights of Automatic Interplanetary Stations Zond-1, Zond-2, Zond-3, Luna-5, Luna-6. NASA translation no. ST-CR-IS-10655.



23 September 1963: Revised Soviet Lunar Project

On 23 September 1963 Korolev submitted a new plan for a human lunar landing program, revised from the earlier L-1 circumlunar project. It incorporated new spacecraft to allow reconnaissance from orbit, landing and extended human exploration of the Moon's surface with a large rover. The plan was described briefly by first cosmonaut Yuri Gagarin at the 14th International Astronautical Federation Congress in Paris in October 1963.

The sequence would begin by sending two men on a circumlunar flyby mission (L-1). Six launches of the Soyuz booster would be used to orbit a lunar rocket stage, four tankers to fully fuel the rocket, and the crew, who would not leave the ground until everything else was ready. The rocket would then place the spacecraft on its lunar trajectory. The crew would use movie cameras and scientific instruments to study the Moon's surface during the flyby, which would be at from 1,000 to 20,000 km from the lunar surface. Total flight time was 7 to 8 days. The return capsule would re-enter the earth's atmosphere at 11 km/sec and land by parachute. Total mass in Earth orbit would be 23,000 kg, of which the Soyuz capsule mass was to be 5,100 kg.

Next came a project to land a remote-controlled nuclear-powered rover (L-2) on the Moon. This is a forerunner of the Lunokhod rovers of the 1970's. It would use components developed for the L1 project and was intended to study the lunar surface and to help select suitable landing sites for later human flights. The rover would carry a radio beacon to guide pilots for precision landings. Data to be returned would include panoramic images, regolith relief, microscopic structure and mechanical properties, magnetic fields, cosmic rays and solar insolation. The rover would have a maximum speed of 4 km/hour and a range of 2,500 km. It would brake to a direct landing at a speed of only 2 to 4 m/s on the surface of the Moon without using a lunar parking orbit.

Korolev's lunar lander (L-3) was designed to make a direct lunar landing following assembly in Earth orbit. The 200 tonne L-3 spacecraft used three N1 launches and one Soyuz launch to assemble in orbit. The first N1 launch would orbit the main spacecraft, partly fueled.

Two more launches would carry tankers to complete the fueling. Then the Soyuz booster would deliver the crew in the L-1 Earth-return capsule. They would dock automatically, and when all was ready the lunar voyage would commence. The lunar landing stage would have a mass of 21 tonnes. The stage would use variable-thrust engines to make a soft landing at 2-4 m/s on the surface. As with Apollo, the descent stage would be left on the Moon. The L-3 mission would last from 10 to 17 days, with 5 to 10 days on the Moon. Unfortunately for Korolev the L-3 was not authorised in this form. Two years later it was resurrected belatedly in a last attempt to beat the Americans to the Moon, but the version redesigned for this program would need only a single N1 launch and carried just a one person lander.

The lunar orbit mission (L-4) would have carried two to three cosmonauts into lunar orbit for an extended survey and mapping program. The 75 tonne L-4 complex would be placed into orbit in a single N1 launch.

The heavy lunar rover (L-5) would allow extended human exploration of the Moon's surface. It would provide living accommodation for three cosmonauts and 3,500 kg of supplies and would have a maximum speed of 20 km/hour. The crews would be landed using the L-3 system. The L-5 would have a mass of 5.5 tonnes and would be guided to a precision landing by a beacon on a previously landed L-2 rover.



23 November 1963: Apollo Working Paper 1100

The Apollo hardware design evolved during the early 1960s, settling on a two spacecraft, lunar orbit rendezvous system. As planning for Apollo moved beyond purely engineering matters, landing site selection emerged as an important but complex issue. Early deliberations (Table 7, Figure 18) are described in Apollo Working Paper 1100 (MSC 1963), released the day after President Kennedy was assassinated.

Safety was the overriding concern. A site had to be level and smooth enough for a safe landing, and the approach had to be free of obstacles. For the early landing missions a fundamental requirement was for a "free-return" trajectory, which would allow crew recovery if a system failure prevented entry into lunar orbit. The spacecraft would loop around the Moon, using lunar gravity to direct the craft back to Earth. The dynamical limitations imposed by this rule restricted landings to within 5° north or south of the lunar equator. Another constraint arose from the lunar orbit rendezvous mission design. For the landed module to rendezvous with its orbiting counterpart, the orbit had to cross the landing site. Lunar rotation would carry the lander away from the orbit track if the site was too far from the equator. This constraint was relaxed for later missions.

Longitude constraints derived from navigation during the final approach and descent to the landing site. The crew would observe lunar surface landmarks during final approach to provide data from which the precise orbit and any necessary corrections could be calculated back on Earth.

Table 7. Apollo Working Paper 1100: Apollo landing sites.			
map designation	position	description	concerns
first set of four sites			
A	2.66° N, 3.66° E	Sinus Medii near Triesnecker	too rough
B	5.1° N, 14.2° W	mare area near Gambart with Copernicus rays	too rough
C	3.0° S, 36.0° W	Oceanus Procellarum with mare ridges	too rough, few landmarks
D	3.0° S, 44.0° W	mare-filled crater near Flamsteed	too far west
second set of five sites			
I	1.75° N, 36.9° E	eastern Mare Tranquillitatis, near highlands	none
III	1.2° N, 28.4° E	Mare Tranquillitatis near Maskelyne	few landmarks
VI	0.5° S, 1.5° W	Sinus Medii	none
VII	2.75° N, 13.25° W	mare area near Gambart with Copernicus rays	none
IX	1.1° S, 31.5° W	Oceanus Procellarum near Lansberg	none
third set of six sites			
E	2.8° S, 8.5° W	mare area near Lalande	none
II	0.0° N, 31.0° E	Mare Tranquillitatis west of Censorinus	none
VIII	2.4° N, 28.25° W	Oceanus Procellarum near Lansberg	none
IV	0.2° N, 24.2° E	Mare Tranquillitatis near Moltke	none
V	0.33° N, 12.8° E	smooth area in highlands, only highland site	too rough
X	1.2° S, 41.5° W	Oceanus Procellarum near Flamsteed	few landmarks

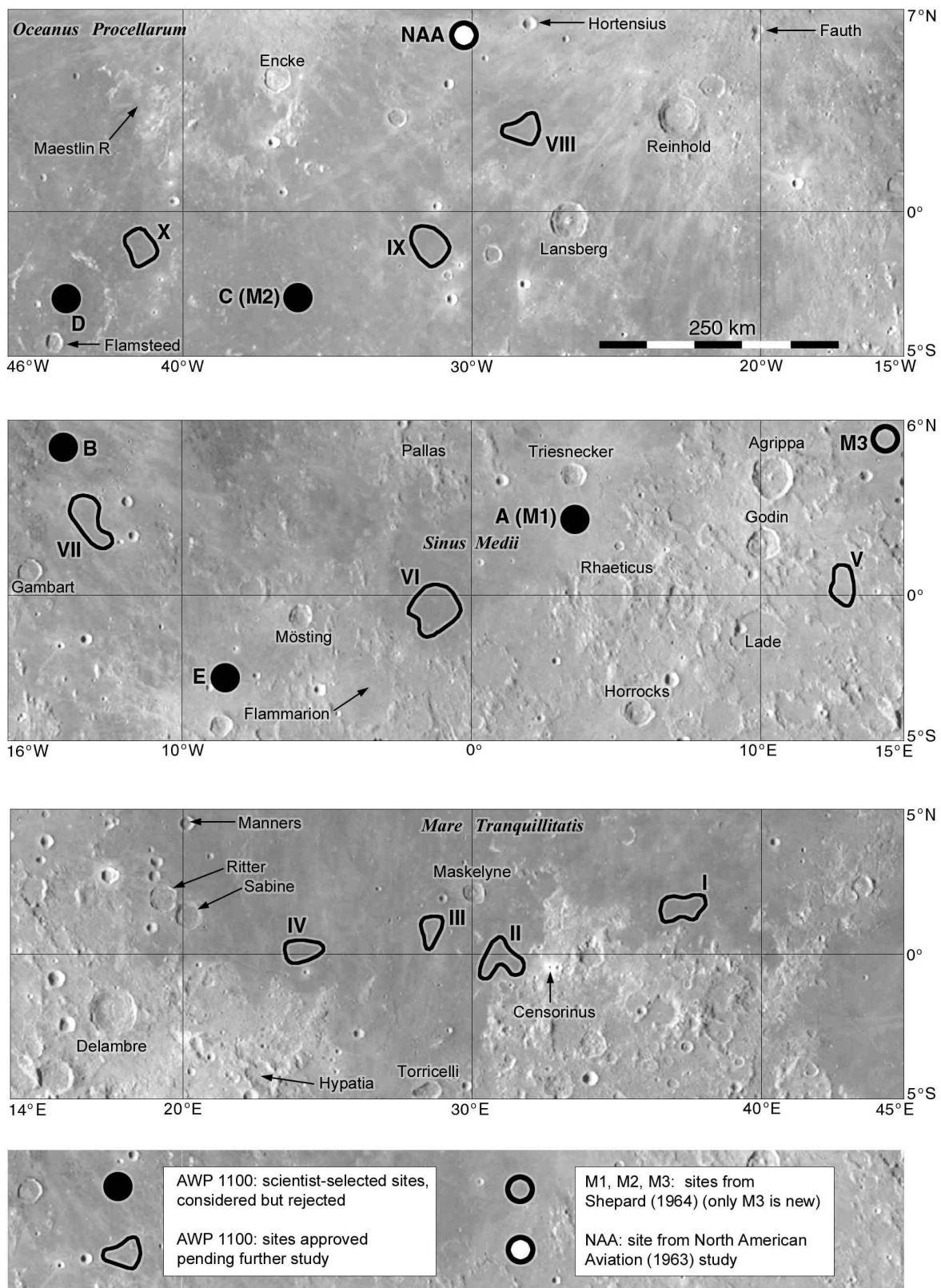


Figure 18. Apollo candidate landing sites from Apollo Working Paper 1100 (Table 7) and contemporary studies. The base image is an LROC wide angle mosaic. For scale, 1° of latitude or along the equator spans 30 km.

This required the astronauts to make five sightings on prominent features east of the landing site after the spacecraft emerged from the eastern limb following the farside radio blackout. Feature positions on available maps were uncertain everywhere but worse near the limbs, and time was needed to obtain and process the sightings, so the early landings could take place no farther east than 40° E. A similar argument applied in the west, since after lunar take-off the ascending LM had to determine its orbit to join up with the orbiting CSM. These considerations restricted the Apollo landing zone to a strip extending 300 km north to south and about 2400 km east to west.

Within this zone geology became an important factor in the choice of landing sites (MSC, 1963; Cappellari, 1972; Compton, 1989). At first, landing 'areas' about 1° across (30 km diameter) were chosen from the best lunar maps available at the time (primarily the early LAC sheets, Figure 4B). These areas lacked prominent craters and appeared to have acceptable slopes.

In mid-1963 the Space Environment Division at the Manned Spacecraft Center in Houston (MSC, later to become the Johnson Space Center) chose four scientifically interesting areas in the landing zone from a list put together by lunar scientists (A, B, C, D in Table 7). Shortly afterwards five more areas were picked for further study (I, III, VI, VII, IX; the order is that given in Table IV of Apollo Working Paper 1100). Finally an additional six sites were examined late in 1963. The lettered sites were dropped and the remaining ten sites (roman numerals) were 'recommended... subject to reconnaissance verification'. The numerals are ordered from east to west, and all fifteen sites are shown in Figure 18. Small irregular outlines (roman numerals) delineate the ten sites approved at that time, pending further study. Solid black circles (letter designations) are other sites considered but rejected.

Other sites were also considered in this period. A paper by astronaut Alan B. Shepard (1964) illustrated three other sites (M1, M2, M3 in Figure 18), only the last of which was new and is shown as an open circle. A report from North American Aviation (1963) added an additional site from a hypothetical mission operations study (NAA in Figure 18). The region considered for landing extended from 0° to 10° N and from 20° to 40° W, and the chosen site was at 6.0° N, 30.3° W, between Copernicus and Kepler craters and in the general area favoured for Ranger and Surveyor landings because it allowed a simple vertical descent.

Cappellari Jr., J. O., 1972. Where on the Moon? An Apollo Systems Engineering Problem. *The Bell System Technical Journal*, vol. 51, no. 5, pp. 955-1127.

Compton, W. D., 1989. *Where no man has gone before: a history of Apollo lunar exploration missions*. NASA SP-4214. Washington, D.C.: National Aeronautics and Space Administration.

MSC, 1963. *Environmental factors involved in the choice of lunar operational dates and the choice of lunar landing sites*. NASA Project Apollo Working Paper (AWP) No. 1100, Nov. 22, 1963.

North American Aviation, 1963. *Project Apollo mission operations analysis for a typical lunar landing mission*. Report SID 62-379-1, prepared by Operations Analysis Aerospace Science, Space and Information Systems Division, North American Rockwell, Inc., 28 January 1963.

Shepard, A.B., Jr., 1964. The Apollo mission. *Advances in the Astronautical Sciences*, v. 18, pp. 201-211.



30 January 1964: Ranger 6

The earlier Rangers had all been unsuccessful, so hopes for high resolution images of the lunar surface now rested on a third version of the spacecraft. This 'Block 3' Ranger was designed to impact on the Moon, transmitting images during the descent. The landing capsule was replaced by a cluster of improved cameras. Whereas Rangers 3 to 5 would have photographed only a small area each, missions 6 to 9 were designed to cover a much larger area with increased high resolution coverage just prior to impact. Additional Rangers were considered for a time but were abandoned in favour of more capable orbiting spacecraft.

The 381 kg spacecraft comprised a hexagonal aluminum base 1.5 m across topped by a truncated cone which held the cameras and a cylindrical low gain antenna. Two solar panels, each 74 by 154 cm, extended from opposite edges of the base, with a high gain dish antenna at one of the other corners of the base. The spacecraft was 3.6m high. The mid-course trajectory correction was performed by a hydrazine engine. Attitude control was enabled by nitrogen gas jets coupled to gyros and Sun and Earth sensors. Power was provided by the solar cells and batteries.

Ranger 6 was launched at 15:49 UT on 30 January 1964 with an Agena booster. After a partial parking orbit the Agena reignited to send the spacecraft to the Moon. A successful midcourse trajectory correction was commanded from the ground early in the flight, without which the spacecraft would have flown past the Moon without impacting. At 9:25 UT on February 2, 1964, 65.5 hours after launch, Ranger 6 struck the Moon at roughly 9.4° N, 21.5° E, close to its target in the western part of Mare Tranquillitatis. Everything but the cameras worked perfectly, but no images were taken because of a failure in the TV power system when it was accidentally turned on about 2 minutes after launch during the booster separation event. The loss of Ranger 6 resulted in considerable criticism of NASA and JPL. Images would have extended from Copernicus crater to the impact point (Figure 19).

Rangers 3 and 4 had been targeted purely on dynamical grounds (Figure 15C), and Ranger 5 had been given several potential targets (Figure 16B). For this new mission, Apollo officials were consulted about appropriate targets but showed no interest, anticipating better images from future orbiters. An unsolicited letter from an interested member of the public proposed several scientifically interesting sites (E. A. Whitaker, personal communication), which were considered and rejected. If no suitable mare target could be identified for the launch date, a flyby over the western limb to image part of the far side would be considered (Curkendall *et al.*, 1964; JPL, 1966). The task of impact site selection fell to Ewen Whitaker of the Lunar and Planetary Laboratory, University of Arizona. In deference to Apollo a mare site within 10° of the equator was selected, as a mare would inevitably be the first landing site. Launch timing and illumination conditions made Mare Tranquillitatis the preferred target, and Whitaker selected 8.5° N, 21.0° E as the target point, in western Mare Tranquillitatis between the craters Ross and Arago (Figure 20A). An alternative site at 13° N, 3° E in Mare Vaporum (Figures 19B, 19C) was also selected, 35° from the terminator at the expected impact time, in case analysis showed that the Mare Tranquillitatis site was too close to the terminator and might lead to an impact in a poorly lit or unlit area.

After launch but before the midcourse correction, the trajectory would have taken the spacecraft over the western limb and far side at an altitude of 812 km with closest approach over 10° S, 168° W, giving excellent imaging coverage of the far side, largely covering the region not seen by Luna 3 (Figure 11C). Before the last course correction (terminal maneuver) the impact estimate was 8.00° N, 20.11° E (Curkendall *et al.*, 1964; JPL, 1966). Tracking indicated an impact about 30 km northeast of the target at 9.33° N, 21.52° E, also reported as 9.4° N, 21.5° E, with uncertainties of about one degree (30 km). Prior to Lunar Reconnaissance Orbiter (LRO), no spacecraft images were capable of resolving the impact crater, though Stooke (2007) suggested that an ejecta deposit near the tracking position, seen in Clementine long wavelength infrared images, might be the impact site (Figure 20B). This was 6 km from the tracking position but well within the roughly 15 km uncertainty. A rayed crater at 9.386° N, 21.481° E (Plescia *et al.*, 2026; Wagner *et al.*, 2017) has been identified in LRO images as the Ranger 6 impact crater (Figure 20D).

Curkendall, D. W., Hamilton, T. W., Kirhofer, W. E. *et al.*, 1964. *The Ranger VI flight path and its determination from tracking data*. NASA-CR-60056, report no. JPL-TR-32-605. Pasadena: Jet Propulsion Laboratory, 15 December 1964.

JPL, 1966. *Ranger VI mission description and performance*. JPL Tech. Rep. 32-699. Pasadena: Jet Propulsion Laboratory, 15 December 1966.

Plescia, J.B., Robinson, M.S., Wagner, R. and Baldrige, R., 2016. Ranger and Apollo S-IVB spacecraft impact craters. *Planetary and Space Science*, v. 124, pp. 15-35. <https://doi.org/10.1016/j.pss.2016.01.002>

Wagner, R.V., Nelson, D.M., Plescia, J.B. *et al.*, 2017. Coordinates of anthropogenic features on the Moon. *Icarus*, v. 283, pp.92-103. <http://dx.doi.org/10.1016/j.icarus.2016.05.011>



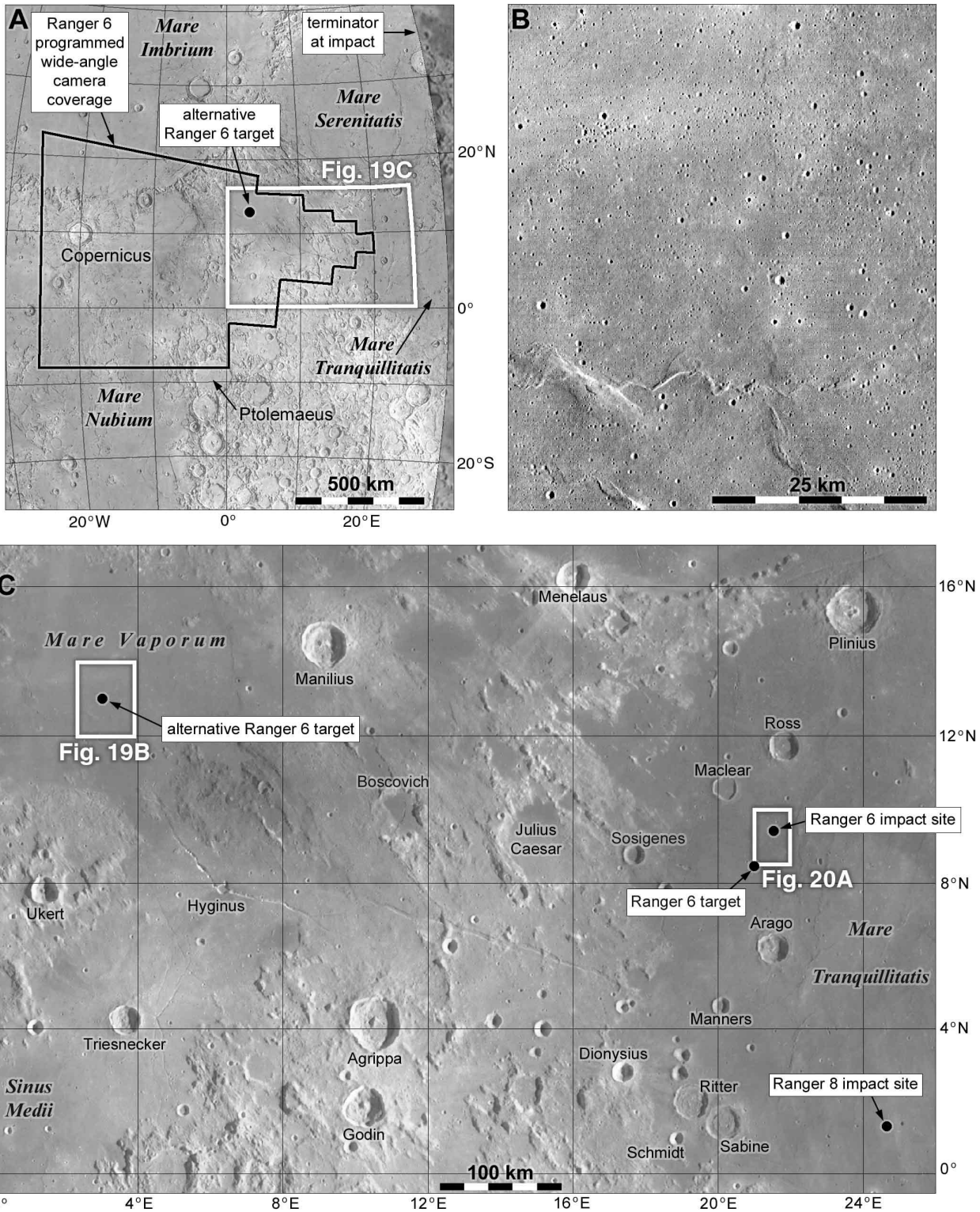


Figure 19. Ranger 6 targets. A: Ranger 6 planned image coverage (E. Whitaker, personal communication). B: Alternative impact target in Mare Vaporum. C: The Ranger 6 target region. B and C: base images are LROC wide angle mosaics.

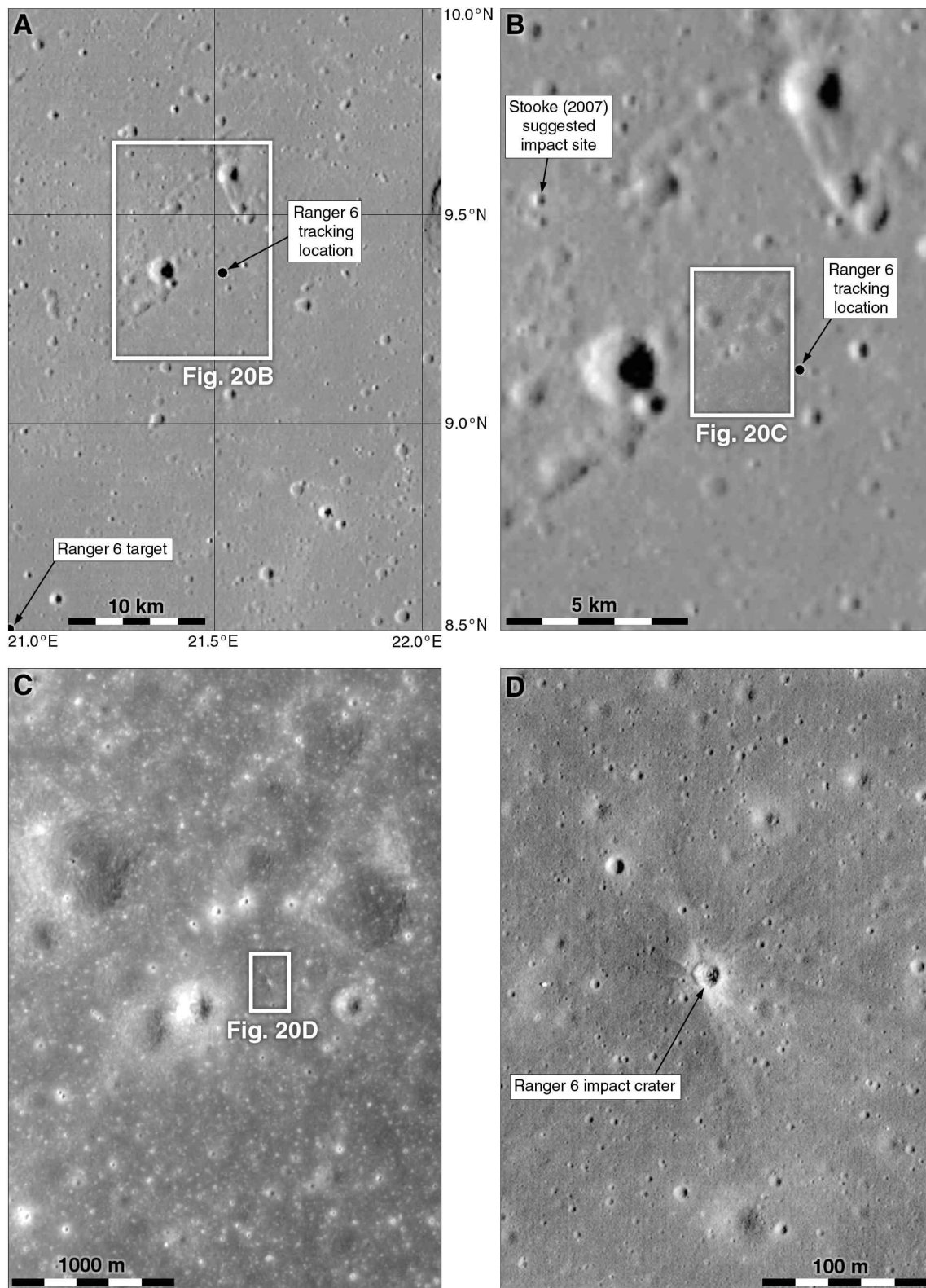


Figure 20: Ranger 6 impact site. A: the Ranger 6 impact target. B: the impact area at higher resolution. A and B are LROC wide angle mosaics. C: Ranger 6 impact site. D: the Ranger 6 impact crater. C and D are from LROC image M144483945R.

21 March 1964: Luna 1964A

Luna 1964A was an attempted lunar landing mission similar to Luna 9. The spacecraft on a SL-6/A-2-e launcher took off from Baikonur but the first stage burn terminated prematurely. The upper stages were destroyed on re-entry into the atmosphere. The landing target would have been in the area shown in Figure 38B.



20 April 1964: Luna 1964B

Luna 1964B was another in the series of attempted lunar landing missions. The spacecraft again failed to reach Earth orbit. 340 seconds after launch from Baikonur the booster's upper stage control system failed and the engine cut off prematurely due to an electrical system failure. The upper stages were destroyed on re-entry. The landing target would have been in the area shown in Figure 38B.



1964: Early Surveyor site planning

As the Surveyor soft landing program took shape, landing sites began to be considered. The Surveyor approach path would give vertical descent profiles (the easiest to deal with) over an elliptical area in the western equatorial part of the nearside (Figure 21). In any one month the vertical descent point moved from southwest to northeast across this ellipse, and over the year that line swept north and south across the ellipse. The first landing would be in this vertical descent area. According to Wilhelms (1993, p. 139), Gene Shoemaker suggested some sites to JPL in January 1964, and a year later he and Elliot Morris proposed a list of five sites. Figure 21 shows several areas proposed as Surveyor targets (Beilock, 1964a, 1964b), probably from Shoemaker's analysis. Most are well outside the Apollo zone described in Apollo Working Paper 1100 (Figure 18). Surveyors which were mobile, or capable of deploying small rovers, were also considered in this period.

Beilock, M., 1964a. Surveyor Lander Mission and Capabilities. *Advances in the Astronautical Sciences*, v. 18, pp. 157-197.

Beilock, M., 1964b. *Surveyor Landing Mission and Capability*. JPL Technical Report No. 32-618, 1 August 1964.

Wilhelms D. E., 1993. *To a Rocky Moon: a geologist's history of lunar exploration*. Tucson: University of Arizona Press.



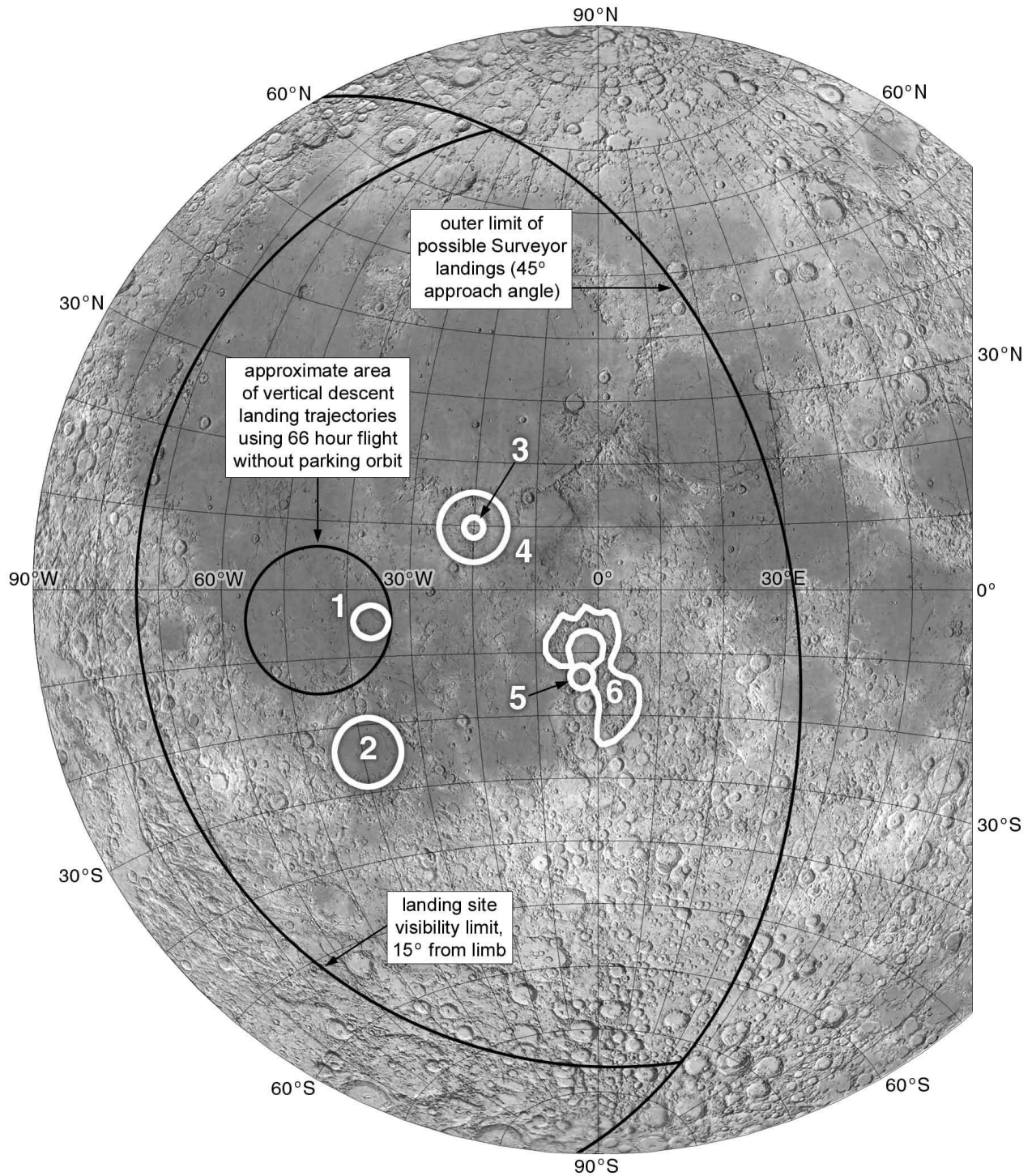


Figure 21: Surveyor landing site constraints and the first suggested targets. 1: Oceanus Procellarum. 2: Mare Humorum. 3: Copernicus floor. 4: Copernicus ejecta. 5: Alphonsus. 6: highlands surrounding Ptolemaeus and Alphonsus.

4 June 1964: Zond 1964A

This flight was intended as a lunar flyby to test the design of the Soviet Zond spacecraft for future Mars missions. This was the same type of spacecraft which eventually flew as Zond 3, not the human crew vehicle intended for lunar missions which later became the Soyuz spacecraft. The mission's SL-6/A-2-e rocket failed during launch from Baikonur and the spacecraft did not achieve Earth orbit. It probably had the same goal as the later Zond 3, of imaging the portion of the far side not seen by Luna 3.



28 July 1964: Ranger 7

After a long series of increasingly controversial failures, this was the first successful Ranger mission. The Atlas-Agena B launcher lifted off at 16:50 UT and placed the 365.7 kg Ranger 7 and its Agena upper stage in a 192 km Earth parking orbit. After 30 minutes the Agena injected the spacecraft into its lunar trajectory and then separated. The solar panels opened and the spacecraft began to control its attitude and switched from the low gain to the high gain antenna. A trajectory correction was performed at 10:27 GMT the next day. Without it, impact would have occurred on the farside on the southern rim of the large impact basin Korolev (Figure 15D). Wollenhaupt *et al.* (1964) give estimated coordinates of 12.2° S, 156.6° W, and the result of the final analysis as 12.4° S, 158.8° W.

Ranger 7 reached the Moon on 31 July. The first image was taken at 13:08 UT at an altitude of 2110 km. The six television cameras took 4308 excellent photographs during the final 17 minutes before impact, the last one having a resolution of 0.5 meters. Pictures were taken from roughly 1800 km to 480 m above the surface. The spacecraft struck the lunar surface 68.6 hours after launch at 13:25 UT with a speed of 2.62 km/s at 10.35° S, 20.18° W, in an area between Mare Nubium and Oceanus Procellarum. The previously unnamed mare area was designated Mare Cognitum (Known Sea) after the mission to highlight the fact that it was the first lunar area to be seen at high resolution. Samples of the images are shown in Figure 24A.

The target was chosen primarily to help characterise the lunar surface at high resolution to assist planning for the Surveyor landers and later Apollo landings, though it was outside the area then being considered for the first landings. To provide adequate lighting for photography, the terminator was about 20° east of the chosen impact point (JPL 1964).

The Ranger 7 target selection was performed by Ewen Whitaker (Lunar and Planetary Laboratory, University of Arizona (Figure 22, Table 8). Again, Apollo officials showed little interest in the selection. Despite this, Whitaker and Kuiper decided that mare sites would be most useful for Apollo. Whitaker plotted the position of the lunar terminator at the predicted impact times for launches on each day of the seven day launch period. The desired sun angle in the highest resolution images was about 20° above the horizon, so for each terminator position Whitaker sought sites about 20° further west as targets. In that narrow longitude range for each day he identified sites which lacked visible obstacles, were darker than their surroundings, hence expected to be relatively free of crater ejecta (referred to in Whitaker's list and in Table 8 as rubble), and also were large enough that the spacecraft had a reasonable chance of impacting within them. The targets submitted to the Ranger project are shown in Table 8, data courtesy of Ewen Whitaker. Figure 22 shows these targets, the full extent of Ranger 7's photographic coverage, and in Figure 22B the region imaged at resolutions better than could be obtained from Earth. The U. S. Air Force produced a set of nested maps of increasing scale to portray the new information, one of which showed the area in which Ranger 7 images surpassed telescopic resolution (Figure 22B).

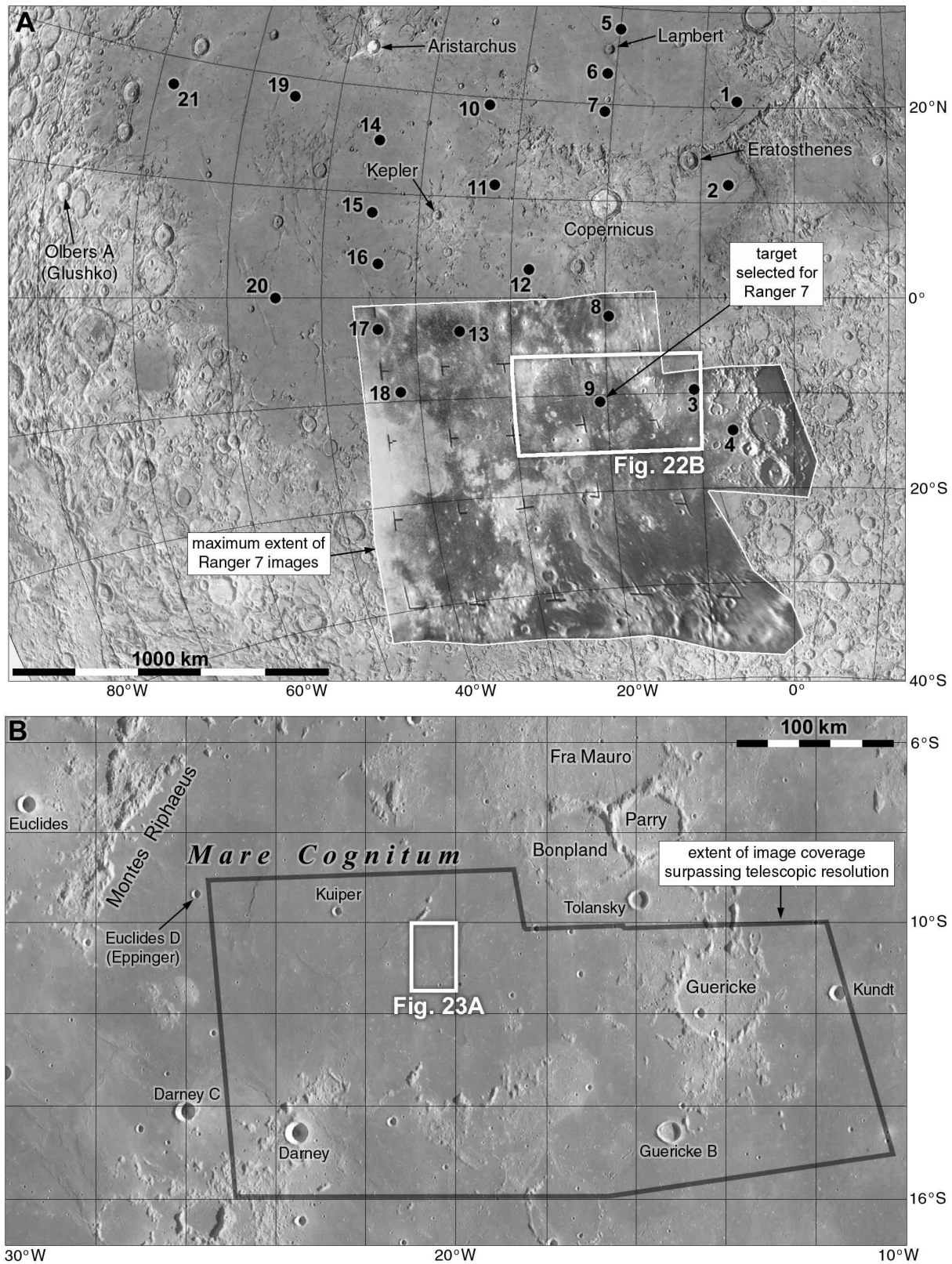


Figure 22: Ranger 7 impact site. A: Landing site candidates for Ranger 7, from Table 8, and image coverage. B: Mare Cognitum impact area, showing the region imaged at better than telescopic resolution. Base image: LROC wide angle mosaic.

Table 8. Ranger 7 targets proposed by Ewen Whitaker				
Launch Date	Site	Location	Solar Altitude	Remarks (BEST: the preferred site for that launch date)
27 July	1	21° N, 7° W	20°	Medium sized area. Eratosthenes and Copernicus rubble. BEST
	2	12° N, 7.5° W	21°	Rather small area, Eratosthenes and Copernicus rubble.
	3	9.5° S, 11° W	25°	Small area, probably relatively free of rubble.
	4	14° S, 7° W	20°	Small area, probably free of rubble.
28 July	5	28° N, 20° W	19°	Large area, probably relatively free of Copernicus rubble.
	6	23° N, 21° W	21°	Medium sized area, Copernicus, Pytheas and Lambert rubble.
	7	19° N, 21° W	22°	Rather small area. Copernicus and Pytheas rubble.
	8	2° S, 19.5° W	21°	Rather small area. Copernicus rubble.
	9	11° S, 21° W	22°	Fairly large area. Probably free of rubble. BEST
29 July	10	19° N, 33° W	22°	Rather small area. Copernicus rubble.
	11	11.5° N, 32° W	21°	Rather small area. Some Copernicus and Kepler rubble.
	12	3° N, 28° W	18°	Medium sized area. Some Copernicus and Kepler rubble.
	13	3° S, 35.5° W	25°	Large area, free of rubble. “Surveyor” site, but rather high solar altitude. BEST
30 July	14	15° N, 45° W	21°	Large area. Some Aristarchus and Kepler rubble.
	15	8.5° N, 45° W	22°	Small area between Kepler rays. Some Kepler rubble.
	16	3° N, 44° W	21°	Medium sized area. Some Kepler rubble.
	17	3° S, 44° W	21°	Medium sized area in old ring. Probably free of rubble.
	18	9° S, 42° W	19°	Fairly large area, free of rubble. BEST
31 July	19	18° N, 55° W	19°	Large area. Some Aristarchus rubble.
	20	0° N, 55° W	20°	Very large area, free of rubble and obstacles. BEST
1 Aug.	21	17° N, 68° W	20°	Large area. Rubble from Olbers A

Another early suggested target for Ranger 7 was the Ranger 6 site, since it might be possible to see the crater produced by the impact. The size of a crater produced by an impact of known energy might reveal useful information on surface strength. The problem here was that only the very last, highest resolution images could usefully resolve such a small crater, and the difficulty of hitting such a small target made this an unrealistic choice. The final selected target was that at 11° S, 21° W in part of Mare Nubium.

The crater Olbers A, referred to in Table 8, is now called Glushko, commemorating the prominent Soviet rocket designer Valentin Petrovich Glushko (1908-1989), designer of the rocket engines which launched the early Sputniks and head of the Soviet space program while it developed its Mir space station in the 1980s. The ‘old ring’ (site 17 in Table 8) is Flamsteed P, the future Surveyor 1 site.

A crater formerly called Bonpland E was renamed Kuiper to commemorate Gerard Kuiper (1905-1973) for his involvement in the Ranger missions and other lunar work. West of Kuiper is the small crater Euclides D (Figure 22B), which was renamed Eppinger by the IAU in 1976 to commemorate German doctor Hans Eppinger. After Eppinger's involvement in medical experiments on humans at Dachau concentration camp was brought to the attention of the Working Group for Planetary System Nomenclature by the Lunar Republic Society in 2002, the name officially reverted to Euclides D in 2009. The Lunar Republic Society was set up to sell plots of lunar land, a concept without legal standing but popular as a novelty item.

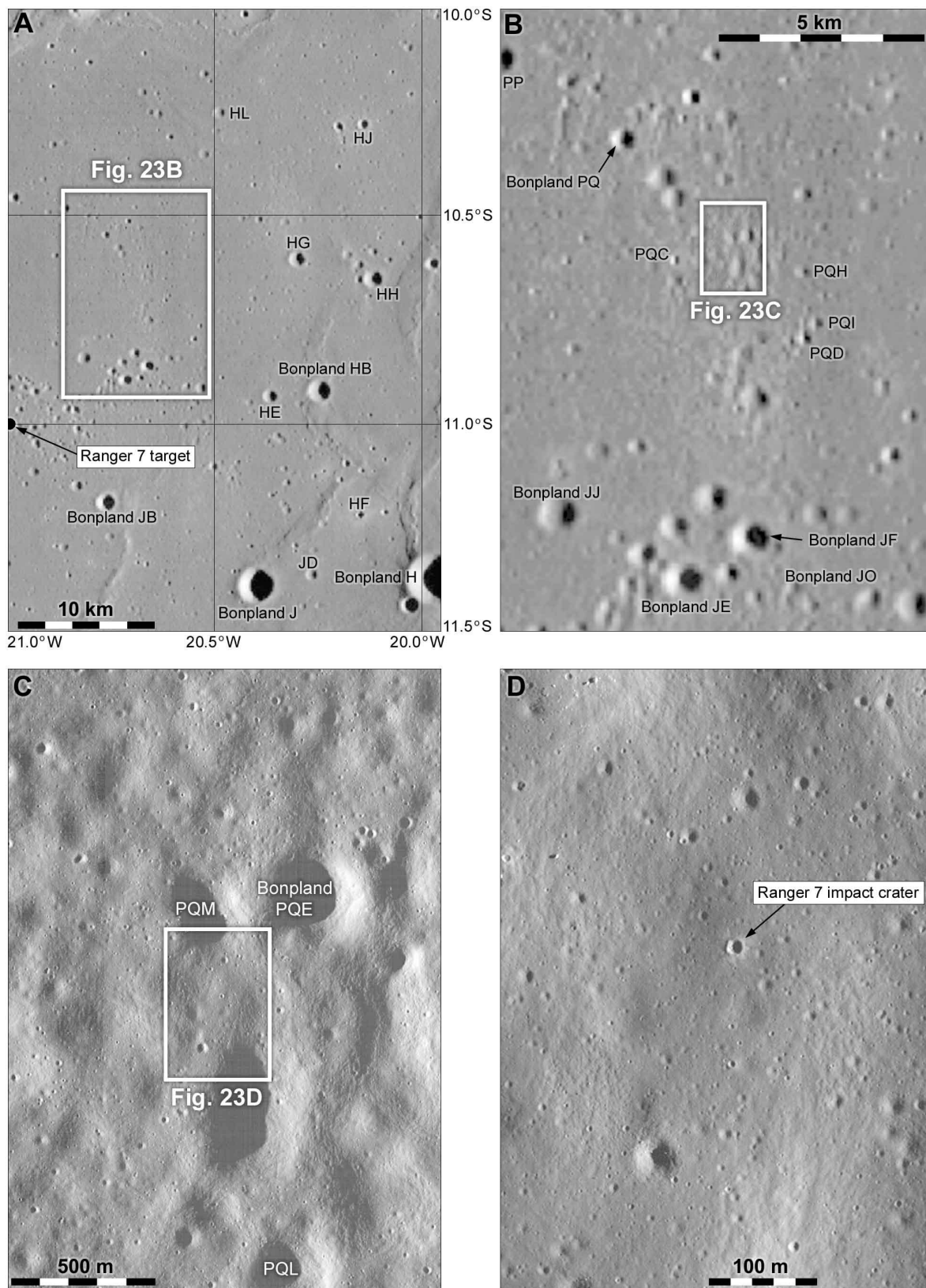


Figure 23: The Ranger 7 impact site. A, B: Ranger 7 region in LROC WAC mosaics. C, D: Ranger 7 impact crater. C is part of LROC image M132963565R. D is part of LROC image M147116569L.

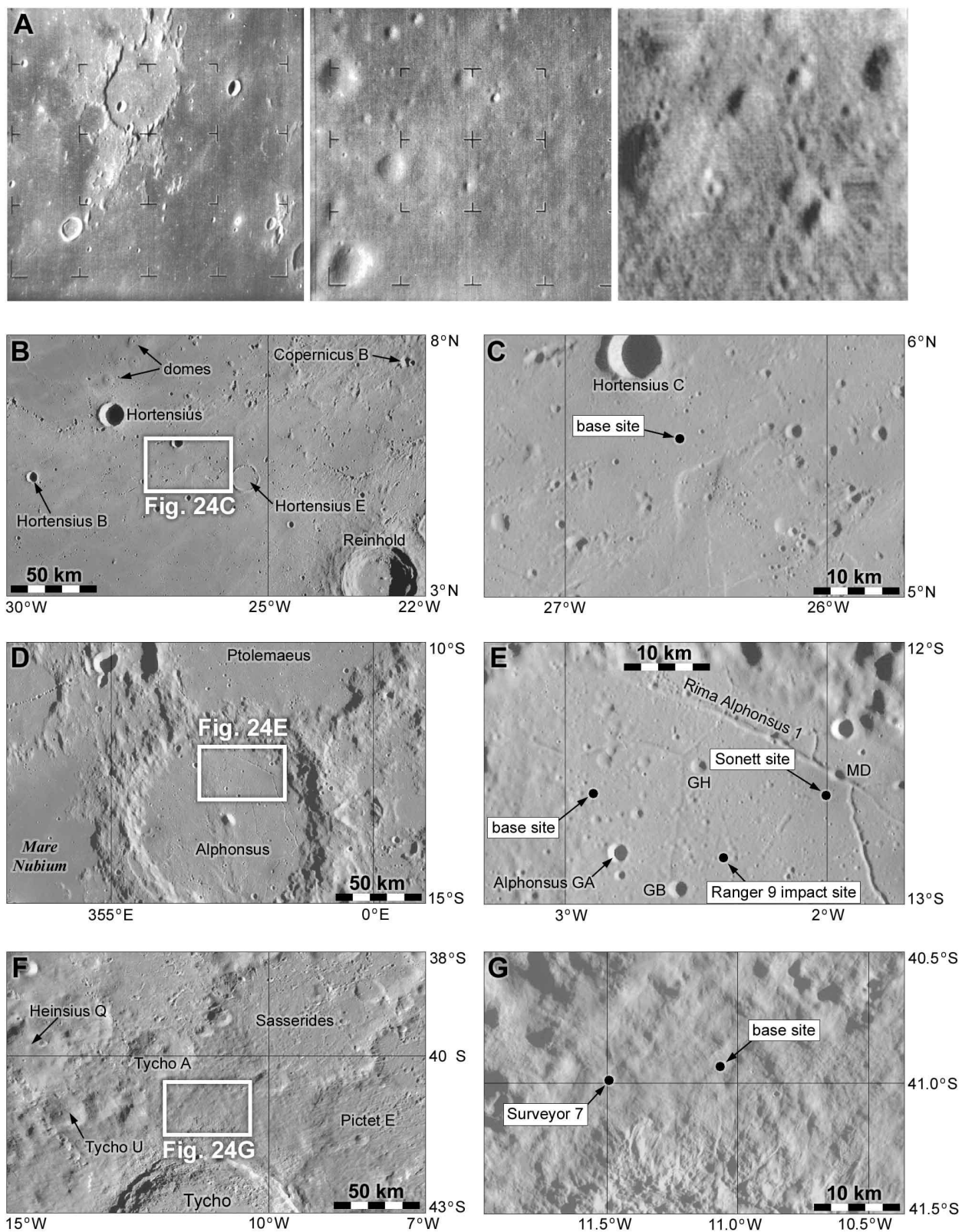


Figure 24. Ranger 7 images and Boeing lunar base planning. A: representative Ranger 7 images. B-G: Boeing lunar base sites from Table 9.

The three images in Figure 24A were taken by Ranger 7 as it descended, from heights of 1335 km (left), 14.7 km (centre) and 1.0 km (right) respectively. The dark lines are reseau marks, intended to help make accurate measurements from hardcopy images. The image at right was one of the last pictures taken before impact. The impact crater was first identified by Ewan Whitaker in Apollo 16 panoramic camera frame 5435 (Whitaker, 1972). Figure 23 shows the 12 m diameter impact crater visible in LRO images at 10.634° S, 20.667° W (Plescia *et al.*, 2016; Wagner *et al.*, 2017). Figure 23 shows the Ranger 7 impact area and impact crater. Ranger 6 was tracked using its radio signal, with limited accuracy, but the Ranger 7 impact site could be located almost exactly using its highest resolution images.

JPL, 1964. *Ranger VII Part I. Mission description and performance*, Jet Propulsion Laboratory Tech. Rep. 32-700. Pasadena: Jet Propulsion Laboratory.

Plescia, J.B., Robinson, M.S., Wagner, R. and Baldrige, R., 2016. Ranger and Apollo S-IVB spacecraft impact craters. *Planetary and Space Science*, v. 124, pp. 15-35. <https://doi.org/10.1016/j.pss.2016.01.002>

Wagner, R.V., Nelson, D.M., Plescia, J.B. *et al.*, 2017. Coordinates of anthropogenic features on the Moon. *Icarus*, v. 283, pp.92-103. <http://dx.doi.org/10.1016/j.icarus.2016.05.011>

Whitaker, E. A., 1972. Artificial lunar impact craters: four new identifications. *Apollo 16 Preliminary Science Report*, NASA SP-315, pp. 29-39 to 29-45. Washington, D.C.: NASA.

Wollenhaupt, W. R., Trask, D. W., Sjogren, W. L. *et al.*, 1964. *Ranger VII flight path and its determination from tracking data*. JPL Technical Report 32-694. Pasadena: Jet Propulsion Laboratory.



3 August 1964: Official Soviet Lunar Project

Despite earlier planning by Korolev and the other Chief Designers, the Soviet Union had not officially sanctioned the proposed lunar missions. As it became clear that Apollo was progressing on schedule and might very well succeed, a belated Soviet response was put together. On 3 August 1964 Command number 655-268 issued by the Central Committee of the Communist Party authorised both Korolev and his rival Vladimir N. Chelomei to proceed with their separate moon projects.

Chelomei was to develop a new three-stage UR-500K launcher and the LK-1 circumlunar spacecraft. The advanced design had already been completed informally. Twelve LK-1's would be built in 1965 and 1966 and would first fly in 1967. The 17 tonne capsule looked similar to the Apollo Command Module, but at 2.8 m diameter was smaller than the 3.9 m diameter Apollo module. LK-1 would be launched into an Earth parking orbit by the new launch vehicle. The LK-1's rocket engine would burn to put it on a translunar trajectory and perform any midcourse corrections. The spacecraft would loop around the Moon and return to Earth.

On October 13, 1964, only two months after the decree, Khrushchev was ousted from office and Leonid Brezhnev took his place. This immediately led to a shift of political forces. Some of Chelomei's other projects were cancelled, but his lunar plan was allowed to continue. However, on 25 October 1965 Korolev regained sole responsibility for human lunar flights. The constant infighting and lack of a settled program were major factors in the Soviet Union's failure to land cosmonauts on the Moon.



1964: Boeing Lunar Base Study

Boeing conducted a study of lunar exploration options after the first landing (NASA, 1964), noting that the expense of a single landing implied some further exploration in order to obtain a suitable return on the nation's investment.

They developed plans for crew sizes varying between three and eighteen, with surface operations lasting between three months and two years. The activities would include geological exploration using pressurized rovers on traverses of up to 300 km and lasting up to five days at a time. This might expand later to 500 km and eight days. Other activities would include geophysics investigations, astronomy and experimental synthesis of fuels from lunar resources.

Boeing identified three sites for scientific outposts or bases to support these studies. One would be targeted for each of the three age divisions of geological material described by Hackman and Mason (1961): mare, pre-mare and post-mare. The mare site was near Copernicus, the pre-mare site in the large crater Alphonsus, later chosen as a target for Ranger 9, and the post-mare site was just north of Tycho in the southern highlands, near the Surveyor 7 landing site. These three sites were chosen from the Sonett report (Table 6, Figure 17), except that the longitude of the Alphonsus site is different. The Sonett coordinates position the landing site at one of several dark halo craters thought to be volcanic vents, and the less interesting Boeing location may be a simple mistake. One of the Apollo Working Paper 1100 sites (Table 7, Figure 18) is also near the Copernicus location. These sites are listed in Table 9 and illustrated in Figure 24.

Table 9. Boeing Corporation Lunar Base Sites from NASA (1964)

Site	Location	Notes
A	5.6° N, 26.6° W	Mare site 250 km southwest of Copernicus, an Apollo candidate site with craters, domes and crater rays.
B	12.6° S, 2.9° W	Pre-mare site on the floor of Alphonsus crater, with several rilles (fractures) and the site of gas emissions described by Kozyrev (1962).
C	40.9° S, 11.1° W	Post-mare site on the north flank of Tycho, a recent ray crater

Hackman, R. J. and Mason, A. C., 1961. *Engineer Special Study of the Surface of the Moon*. U. S. Geological Survey, Miscellaneous Geologic Investigations Map I-351.

NASA, 1964. *Initial Concept of Lunar Exploration Systems for Apollo. Volume 1 - Summary*. NASA Contractor Report CR-35, prepared by Boeing Co., Seattle, Washington, March 1964.



17 February 1965: Ranger 8

The second successful Ranger flight was launched at 17:05 UT. The Atlas-Agena B launcher placed the Agena and Ranger 8 in a 185 km parking orbit, then after 14 minutes the Agena made a 90 second burn to put the spacecraft on its lunar trajectory. Several minutes later the Ranger and Agena separated. The spacecraft deployed its solar panels, began its attitude control functions and switched from the low gain to the high-gain antenna by 21:30 UT. On 18 February at 160 000 km from Earth a trajectory correction was performed. An intended manoeuvre to point the cameras more in the direction of flight shortly before imaging began was cancelled to reduce risk and so that the cameras would photograph a greater area of the surface.

Ranger 8 reached the Moon on 20 February. The first image was taken at 9:34 UT at a height of 2510 km. 7137 excellent photographs were obtained over the last 23 minutes before impact. The final image was taken at a height of about 160 m and had a resolution of 1.5 meters. Impact occurred at a speed of 2.6 km/s at 09:57 UT after 64.9 hours of flight. Ranger 8 crashed less than 20 km from its target point in Mare Tranquillitatis at 2.67° N, 24.65° E. Excellent photographs of the craters Delambre, Sabine and Ritter, long fault-bounded valleys and the southern edge of Mare Tranquillitatis were obtained. The images (Figure 27) also showed that a second mare surface was smooth enough to contemplate landing on.

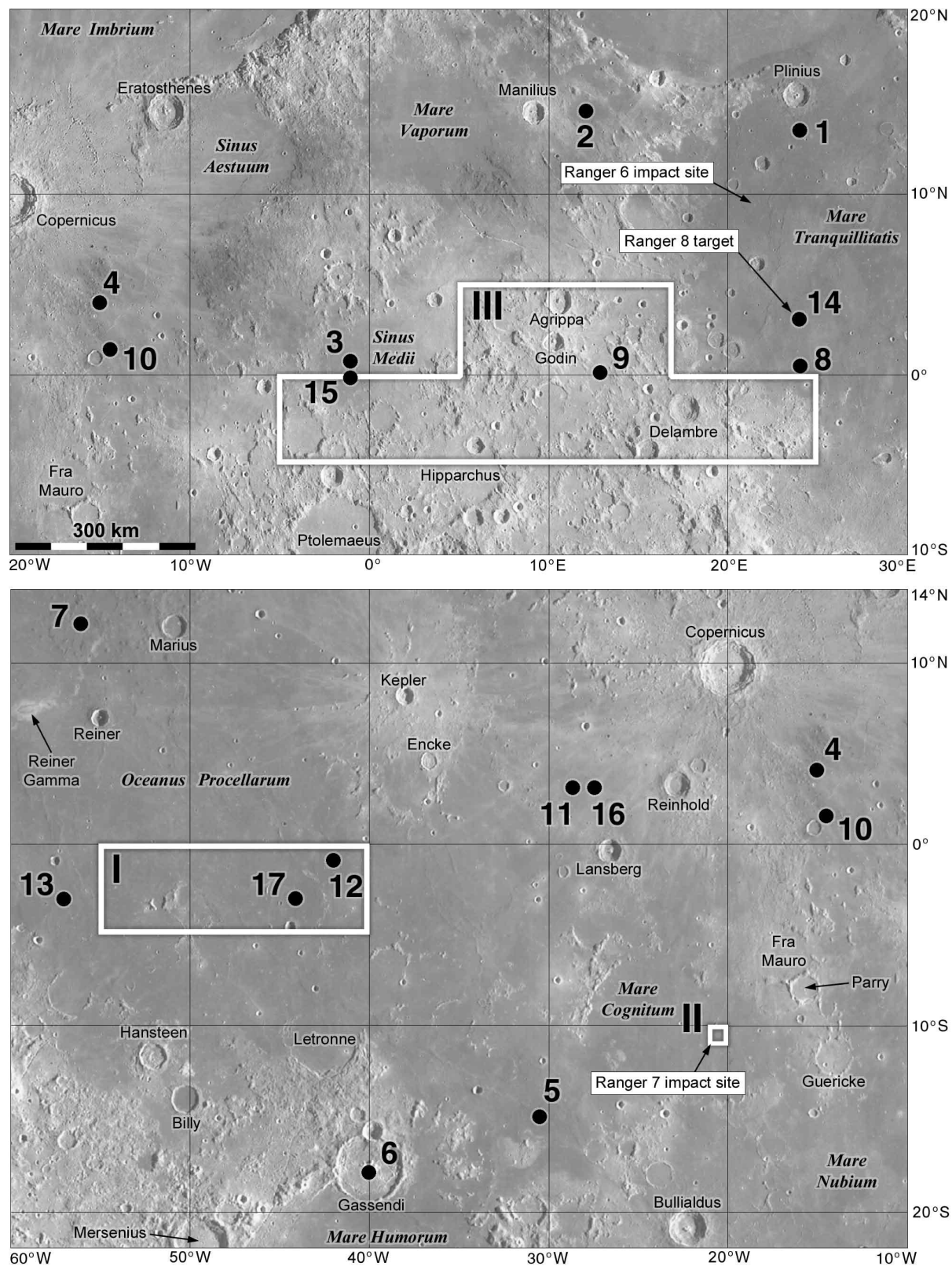


Figure 25: Ranger 8 impact target points from Table 10, and white box areas (I, II, III) suggested by Apollo planners. The base image is an LROC wide angle mosaic.

Ranger 8 impact site selection was more complex than for Ranger 7 (Figure 25, Table 10). Project Apollo officials had shown little interest in the targeting of Rangers 6 and 7, but with the success of the latter they paid more attention to Ranger 8. Their initial suggestions (white boxes in Figure 25) were (I) a ray-free mare region, (II) the Ranger 7 impact crater and (III) a highland region (Hall, 1977). The Ranger 7 impact crater was an unrealistic target, as that of Ranger 6 had been for Ranger 7.

NASA's Homer Newell proposed a list of sites on 19 January 1965 (Table 10a), one for each launch date during the February launch period. Impact had to be near the terminator to assure good relief definition in images, so the site would change each day if launch had to be delayed. George Mueller of the Office of Manned Space Flight noted that many of those sites were outside the near-equatorial Apollo zone of interest, and submitted his own list of sites (Table 10b), mostly close to those from Apollo Working Paper 1100 (Table 7; Figure 18).

Newell and colleagues responded with a compromise list (Table 10c) which included some from each of the previous sources, with minor modifications in two cases. Ranger 8 was launched towards the first target on this list on 17 February. The intrusion of Apollo planners into the Ranger site selection process was controversial, and considerable pressure was applied for Ranger 9 to be targeted primarily for scientific purposes.

Table 10. Ranger 8 target selection			
map designation	launch date	description	location
10a. Newell's list of January 19, 1965:			
1	2/17	Mare Tranquillitatis	13.5° N, 24.0° E
2	2/18	mare patch near Mare Vaporum	14.5° N, 12.0° E
3	2/19	Sinus Medii	0.5° N, 1.0° E
4	2/20	secondary craters near Copernicus	4.0° N, 15.0° W
5	2/21	candidate Surveyor landing site number 5	15.0° S, 30.5° W
6	2/22-23	Gassendi	18.0° S, 40.0° W
7	2/24	volcanic domes near Marius	12.0° N, 56.0° W
10b. Mueller's suggestions, suitable for Apollo:			
8	2/17	Mare Tranquillitatis	0.5° N, 24.0° E
9	2/18	highland region	0.0°, 13.0° E
3	2/19	Sinus Medii	0.5° N, 1.0° W
10	2/20	mare region	1.5° N, 14.5° W
11	2/21	mare region	3.0° N, 28.25° W
12	2/22-23	ray-free mare area	1.0° S, 42.0° W
13	2/24	Oceanus Procellarum	3.0° S, 57.0° W
10c. Compromise list:			
14	2/17	Mare Tranquillitatis	3.0° N, 24.0° E
2	2/18	Mare Vaporum	14.5° N, 12.0° E
15	2/19	Sinus Medii	0.0°, 1.0° W
4	2/20	near Gambart	4.0° N, 15.0° W
16	2/21	near Reinhold	3.0° N, 28.25° W
17	2/22-23	Oceanus Procellarum	3.0° S, 44.0° W
7	2/24	Oceanus Procellarum	12.0° N, 56.0° W

In Figure 25 the white boxes labelled I, II and III are the first target areas suggested by Apollo planners. II is the Ranger 7 impact crater. The numbered points are the sites suggested during three steps in the selection process, as outlined in Table 9. A comparison of this map with Figure 18 reveals several common targets. Sites 4, 8, 9, 10, 11, 12, 15, 16 and 17 are all included in the earlier list of potential Apollo sites. Most are dark mare areas, thought to be smooth, and site 9 is a smooth highland site.

Ranger 8 images covered the southwestern maria (Nubium, Humorum, southern Oceanus Procellarum) at low resolution, and increased in resolution across the highlands east of Ptolemaeus. ACIC again produced a series of maps to document the Ranger 8 mission, one of which is shown in Figure 27B. Ranger 8 approached the Moon more obliquely than Ranger 7 and did not photograph its impact area. A terminal (pre-impact) maneuver to point the cameras at the impact site was rejected because of the inherent risk of failure and because it would decrease surface coverage.

Ranger 8 imaged a large area extending from Mare Humorum to Mare Tranquillitatis (Figure 27A). Only the eastern end of the sequence improved on telescopic resolution. As with Ranger 7, the U.S. Air Force compiled a set of charts from Ranger 8 images, one of which is shown in Figure 27B. Superimposed on that figure is the example of astronaut traverse planning presented by Harrison Schmitt at the Falmouth Conference (NASA, 1965). LEM is the hypothetical landing point of the Lunar Excursion Module, later referred to just as the Lunar Module (LM). The walking traverses visit features of geological interest, craters of different sizes and a boulder field. The LEM position was given as 2.66° N, 24.75° E, using updated coordinates which do not match the grid on the Ranger chart. Three representative Ranger 8 images are shown in Figure 27C. The image at left shows craters Schmidt, Sabine and Ritter and the nearby highlands. The other two images from lower altitudes show the nature of the surface in this area of Mare Tranquillitatis. There was now little doubt that the surface was safe for landings (JPL, 1966).

The Ranger 8 crater (Figure 26D) was the first spacecraft impact crater photographed from orbit, by Lunar Orbiter 2 in frame 070H2. By analogy with natural impacts a bright crater and ejecta deposit were anticipated, so initially the small bright crater craters labelled A and B in Figure 25D were interpreted as candidates for the Ranger 8 impact crater (Boeing, 1967). Crater A was preferred as it appeared to be elongated in the direction of the incoming spacecraft, though this was an artifact caused by a framelet boundary in the Lunar Orbiter image available at the time. Subsequent imaging of Ranger and Apollo impact craters by the Apollo 16 panoramic camera (Whitaker 1972, Plescia *et al.*, 2016)) showed that artificial impact craters are often surrounded by dark or mixed light and dark rays, possibly resulting from residual fuel in the tanks or metallic fragments in the ejecta. This led to the identification of the larger crater as the true Ranger 8 impact crater. Its size is also more in keeping with expectations, about 12.5 m across (Figure 30). Its location is 2.638° S, 24.788° E (Wagner *et al.*, 2017).

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Plescia, J.B., Robinson, M.S., Wagner, R. and Baldrige, R., 2016. Ranger and Apollo S-IVB spacecraft impact craters. *Planetary and Space Science*, v. 124, pp. 15-35. <https://doi.org/10.1016/j.pss.2016.01.002>

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Whitaker, E. A., 1972. Artificial lunar impact craters: four new identifications. *Apollo 16 Preliminary Science Report*, NASA SP-315, pp. 29-39 to 29-45. Washington, D. C.: NASA.



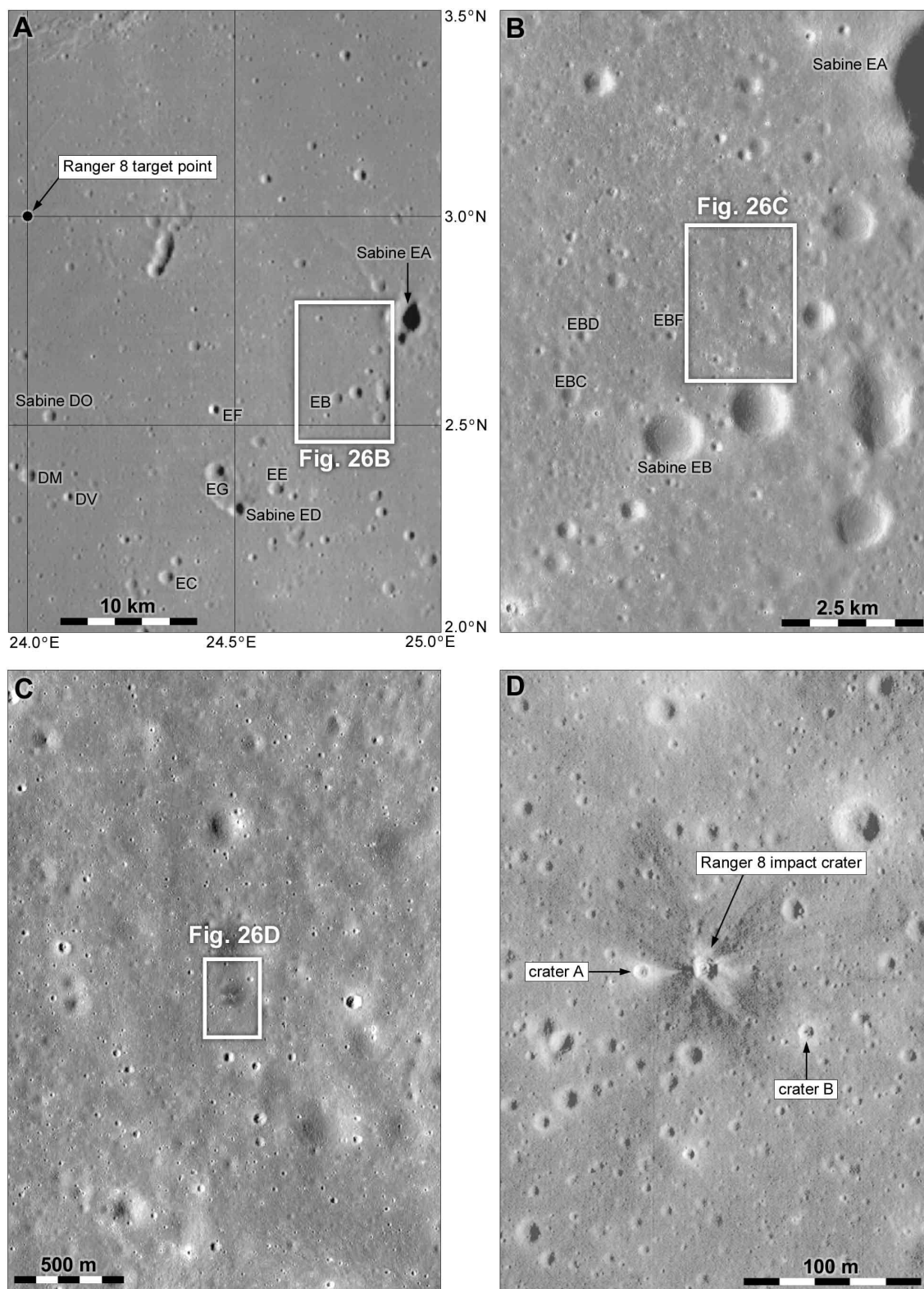


Figure 26: The Ranger 8 impact site. A: the impact region and target point (LROC WAC mosaic). B: the impact site in a mosaic of LROC NAC images. C, D: The Ranger 8 impact crater in LROC NAC image M144463715L. Craters A and B are described in the text.

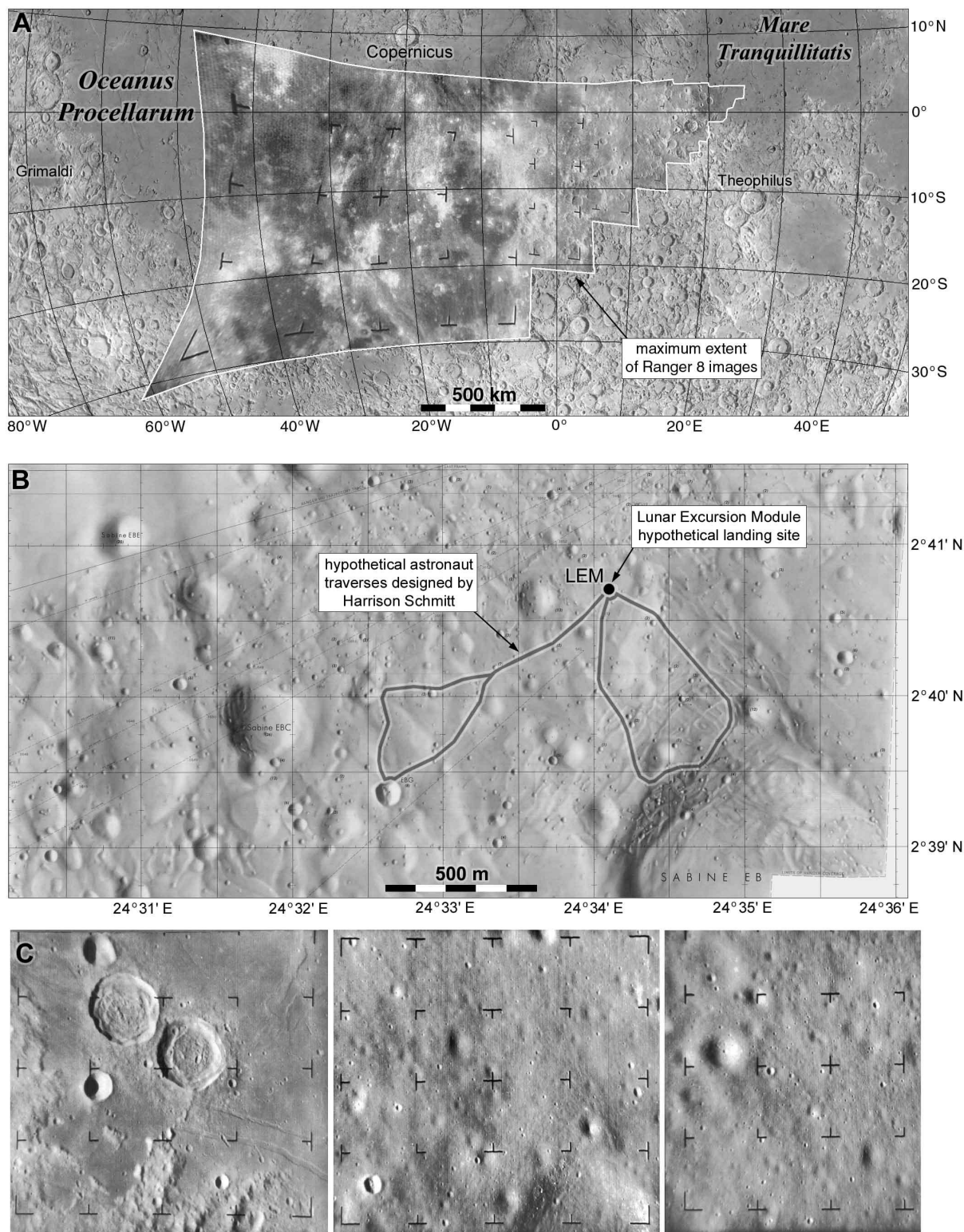


Figure 27: Ranger 8 images. A: total image coverage. B: hypothetical walking traverses designed by Harrison Schmitt (NASA, 1965) to illustrate the planning potential of high resolution images. ACIC Ranger Lunar Chart RLC-11 (*Sabine EB*), original scale 1:5000, 1st edition, March 1966. C: representative Ranger 8 images. The middle image covers the right half of Figure 27B.

12 March 1965: Luna (Cosmos 60)

Cosmos 60 was intended to be a lunar soft-landing mission with a design similar to that of Lunas 4 and 9. The 6530 kg spacecraft was launched from Baikonur at 09:36 UT, but the upper stage engine failed to ignite due to an electrical failure. The stage with the payload remained in Earth orbit and was given the designation Cosmos 60. The lunar target area would have been near the equator in western Oceanus Procellarum (Figure 38B).



21 March 1965: Ranger 9

This was the last of the Ranger missions. The spacecraft was identical to Rangers 6, 7 and 8. Rangers 7 and 8 had provided data useful for Apollo mission planning, so Ranger 9 was used to advance basic lunar science. At a very early stage a target in Sinus Medii was considered for Apollo planning purposes, but a highland or large crater site was preferred for its science value. A prime candidate was the geologically complex crater Alphonsus, in part because on the night of 3-4 November 1958, Nikolai A. Kozyrev at the Crimean Observatory recorded a possible emission of molecular hydrogen at the central peak (Kozyrev, 1962). This was one of the best documented cases of a Transient Lunar Phenomenon (TLP), controversial but possible evidence of a low level of ongoing internal activity. TLPs had also been reported at Aristarchus.

Ranger 9 launched from Cape Canaveral at 21:37 UT on 21 March 1965. The Atlas Agena launcher placed Ranger 9 into a parking orbit at 185 km altitude. A 90 second burn of the Agena placed the spacecraft on its lunar trajectory, and a 31-second mid-course correction was made at 12:30 UT on 23 March. Without the correction, impact would have occurred at 4.078° N, 2.204° W (Table 9 in Vegos *et al.*, 1968)

Ranger 9 reached the Moon on 24 March. After 64.5 hours of flight, impact occurred at 14:08 UT at 12.828° S, 2.387° W in the crater Alphonsus, with a speed of 2.67 km/s. The first image was taken at 13:49 UT at a height of 2363 km. 5814 photographs were transmitted during the final 19 minutes of flight, the last one having a resolution of 0.3 meters from 600 m height (Figure 31A). Some of the images were broadcast live on television in the United States during the final descent. The Ranger 9 impact crater (Figure 29D) showed bright ejecta in Apollo 16 images, but all Ranger craters had mixed bright and dark ejecta in LROC images (Figure 30).

Ranger 9 target selection began with discussions at JPL among scientists and Surveyor and Apollo representatives on 27 February 1965. The scientists, including Eugene Shoemaker, Hal Masursky, Gerard Kuiper and Ewen Whitaker, unanimously agreed that 'Ranger D' (as it was called before launch) should view a non-mare target, either highlands or a site of special scientific interest, closer to the terminator than the earlier Ranger targets to give better shading for topographic interpretation.

Surveyor planners initially preferred an impact in the vertical landing region to be visited by Surveyor 1 (Figures 21, 44A), but this would have been another mare target. Apollo planners supplied a list of sites for each launch date, some outside the Apollo zone if they were scientifically interesting. On 2 March Ray Heacock, Ewen Whitaker and Don Willingham met at JPL to choose preliminary targets, which were then reviewed by Kuiper, Shoemaker and Harold Urey to arrive at a final target. The candidate sites are listed in Table 11 and illustrated in Figure 27A.

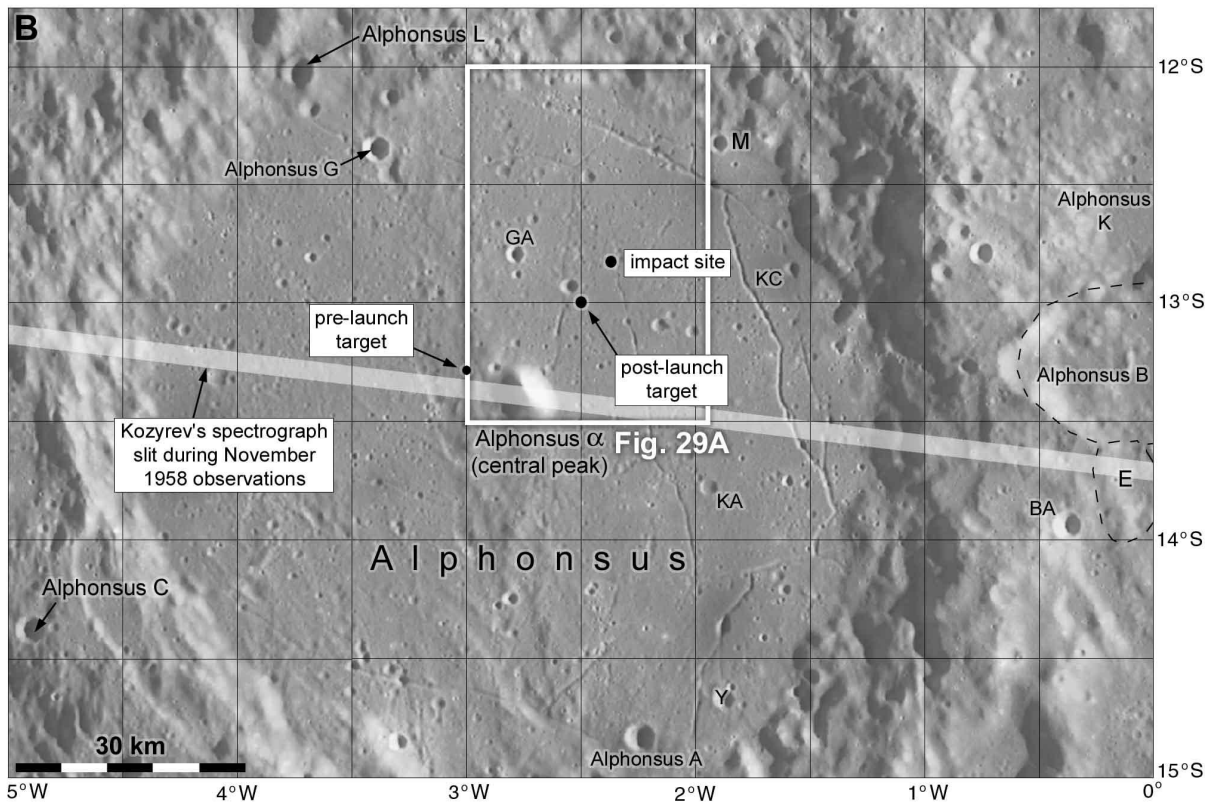
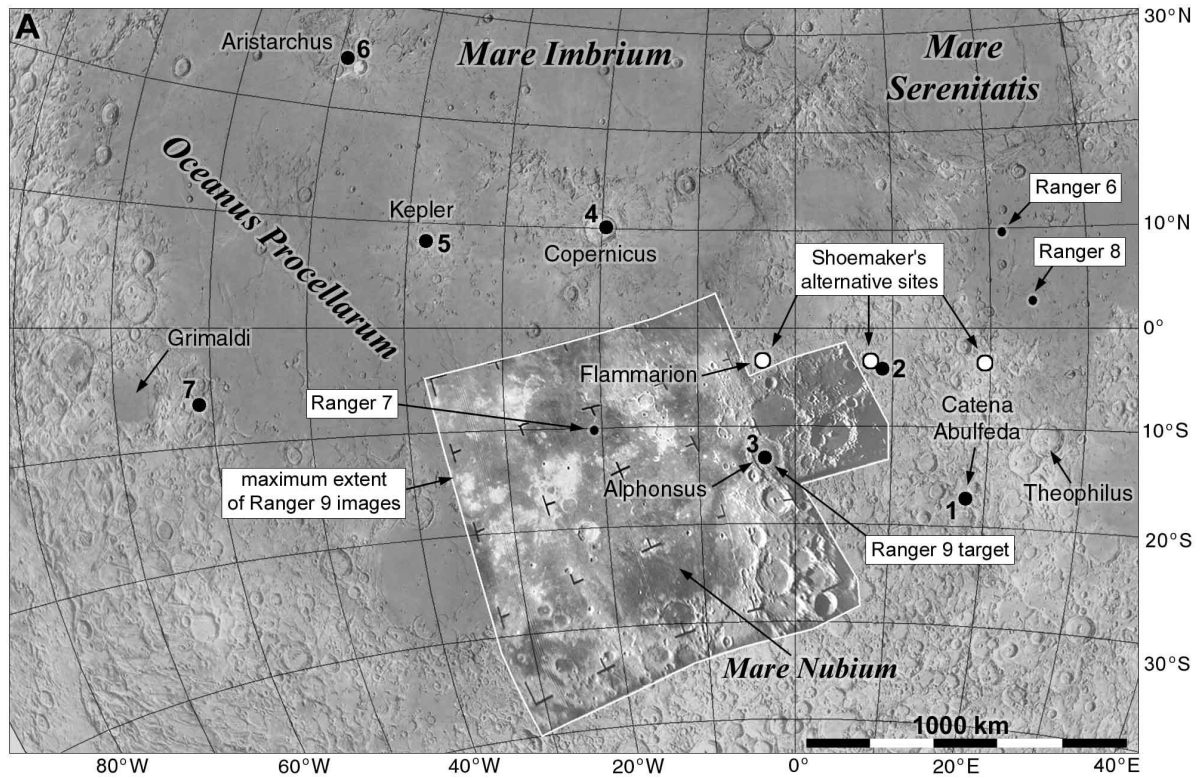


Figure 28: Ranger 9. A: Ranger 9 proposed targets from Table 11 and image coverage. B: Alphonso, showing the target and impact points. The line shows the position of Kozyrev's spectrometer slit during his 1958 observations (Kozyrev, 1962; Smith *et al.*, 1966; Vegos *et al.*, 1968). The image is an LROC wide angle mosaic.

Table 11. Ranger D (Ranger 9) preliminary targets, 2 March 1965.

Site	Launch date	Target point	Distance from terminator	Notes
1	19 March	17.5° S, 18.5° E	14.5°	East end of crater chain (Catena Abulfeda) near Altai scarp, highland target. Not acceptable to Urey, who had no interest in highlands. Shoemaker preferred a highland basin at 3.0° S, 19.3° E for consideration as an Apollo site.
2	20 March	4.3° S, 9.0° E	11.25°	Saunders, a smooth highland basin. Alternate highland site: 3.5° S, 8.0° E. Preferred by Shoemaker for Apollo planning but others would like a more interesting target.
3	21 March	13.3° S, 3.0° W	10.5°	Alphonsus, a large highland crater with suspected volcanic activity (Figure 28). Shoemaker preferred a simpler site in Flammarion at 3.0° S, 3.8° W.
4	22 March	10.0° N, 19.5° W	14.3°	Interior of Copernicus crater.
5	23 March	8.2° N, 37.8° W	20.0°	Kepler crater, the most scientifically interesting site available for this date but small, with little chance of hitting the crater interior.
6	24-25 March	24.5° N, 49.0° W	19.0°	The tip of Schröter's Valley near Aristarchus, a site reported as showing signs of volcanic activity.
7	26 March	7.0° S, 61.5° W	19.0°	Highlands east of Grimaldi, recommended by NASA's Office of Manned Space Flight (OMSF) but of little interest to the scientists.

OMSF had suggested several rough highland targets, or points at the outer edge of crater ejecta deposits. The scientists preferred smoother highland sites or crater interiors. Alphonsus was by far the preferred target, so the first two launch dates were dropped from consideration. There had been no agreement on a target for those days. Aristarchus was the second priority target but Copernicus or Kepler would not be bypassed if launches were possible on those days (Schurmeier, 1965). These targets are illustrated in Figure 28A. The pre-launch target point was modified by the trajectory correction to reduce the likelihood of impacting in the shadow of the central peak.

Ranger 9 struck the surface in a flat area among linear valleys which probably formed over deep fractures (JPL 1966). Those fractures may have provided routes for gas and ash to erupt from greater depths, and some small craters lying along the fractures are thought to be volcanic (*e.g.* Alphonsus MD, Figure 29A). A few large boulders seen in the last images provided evidence that the surface could support at least the weight of a person. The impact point was estimated from motion between the final images.

The Ranger 9 impact crater was not imaged by Lunar Orbiter missions, but was found exactly where it was expected from analysis of the descent images, in Apollo 16 Panoramic Camera frame 4658, taken seven years later (Whitaker, 1972; Plescia *et al.*, 2026; Wagner *et al.*, 2027). Ranger 9 approached from the west, and a deposit of bright ejecta was seen to the east of the impact crater in the Apollo 16 image, but in LROC images it appears partly light and partly dark. The location is 12.828° S, 2.387° W in LRO coordinates. Figure 30 compares all four Ranger impact craters imaged by LRO at both high and low sun angles. The mixed bright and dark ejecta is common to all four craters, but it is also seen in many natural small lunar craters.

Moore (1964), writing after the success of Ranger 7, suggested extending the Ranger project beyond Ranger 9. Additional spacecraft might be used to view earlier Ranger impact craters, landed Surveyor or Apollo hardware, additional terrain types, or Earth from high altitude.

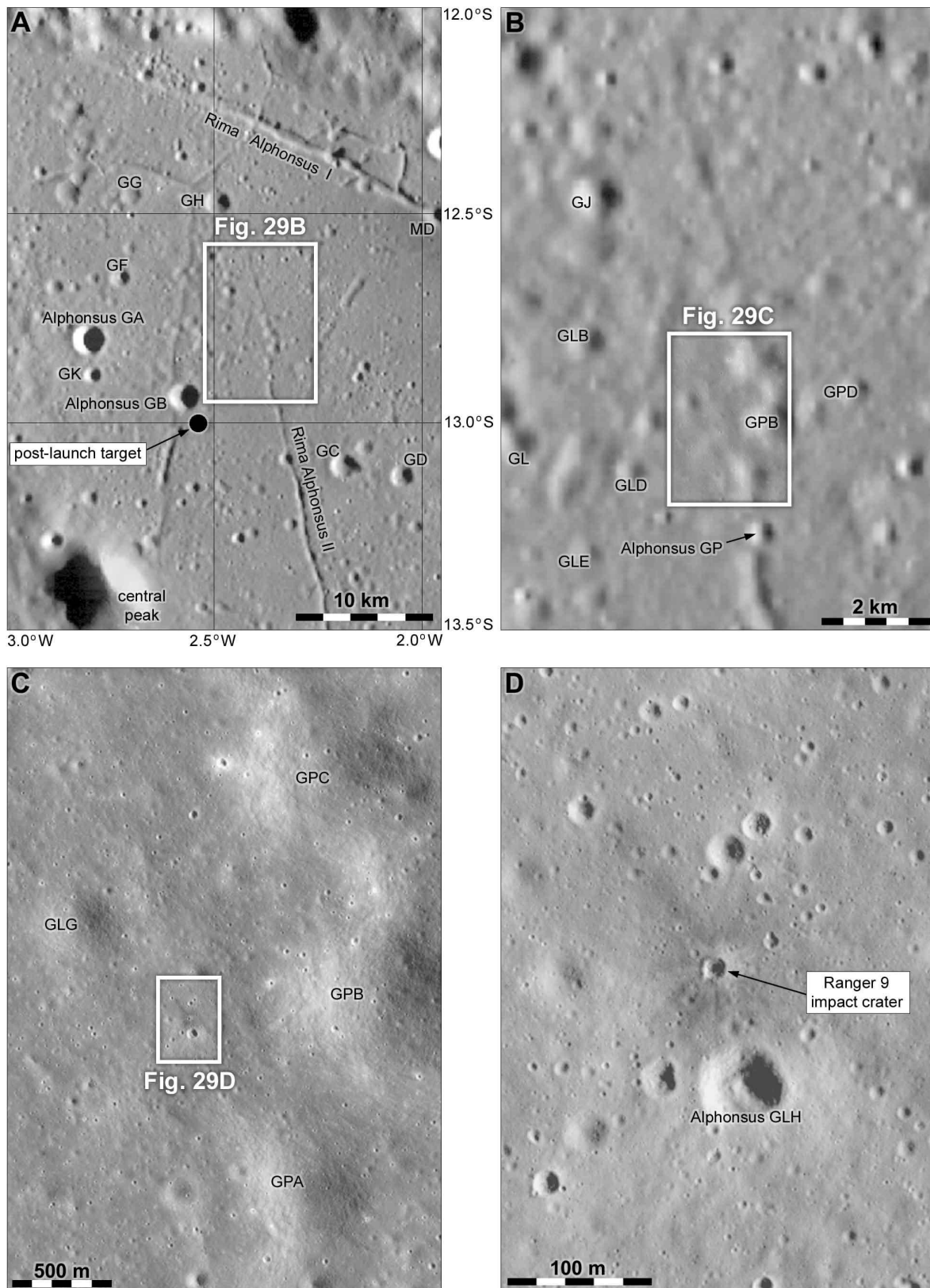
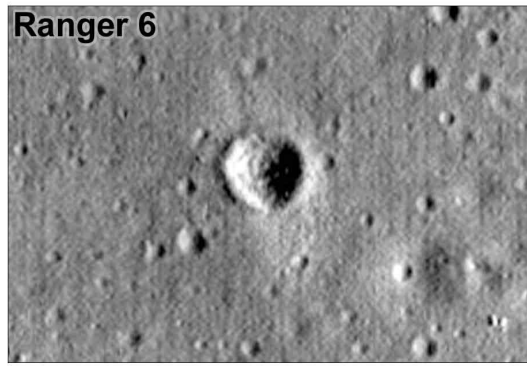
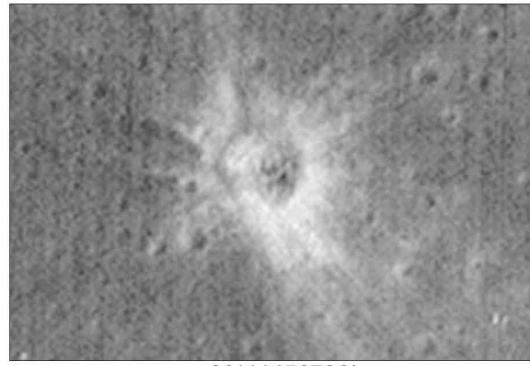


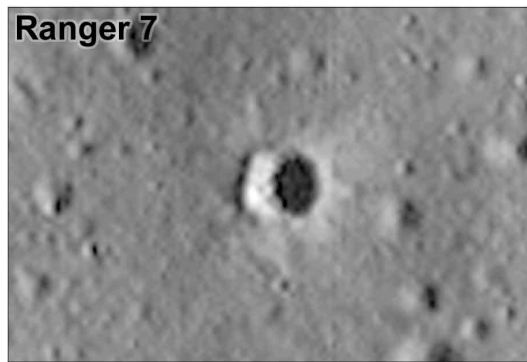
Figure 29. Ranger 9 impact site and crater. A, B : LROC WAC mosaics. C, D : LROC NAC image M129309387R.



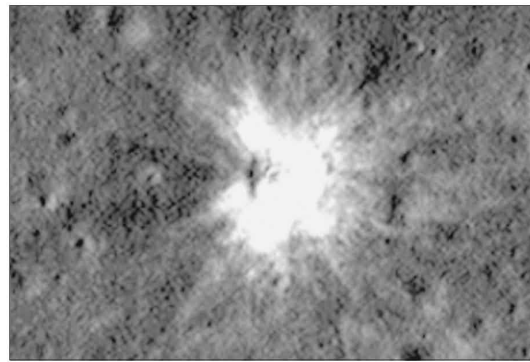
M177494593R



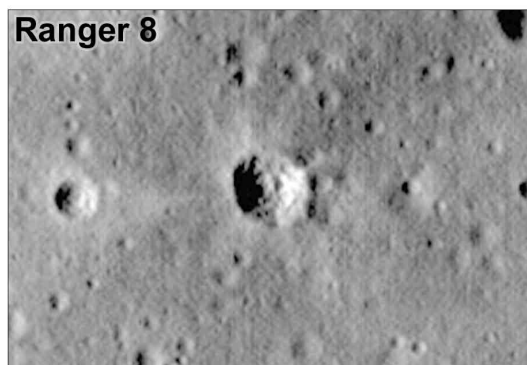
M111456730L



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M153014430L



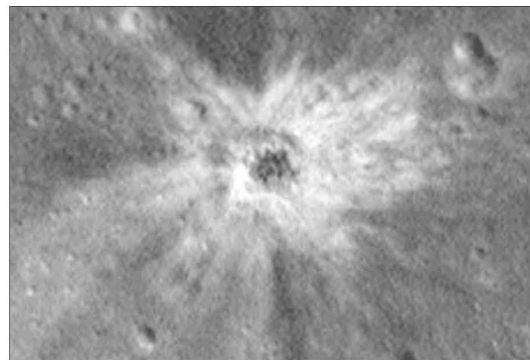
M150355067R



M144463715L



M129309387R



M157607994R

Figure 30. Ranger impact craters imaged by LRO with low and high illumination angles. Each image is 100 m wide, and the craters are about 12 m in diameter.

JPL, 1966. *Ranger VIII and IX. Part II. Experimenters' analyses and interpretations*, JPL Tech. Rep. 32-800. Pasadena: Jet Propulsion Laboratory.

Kozyrev, N. A., 1962. Spectroscopic proofs for existence of volcanic processes on the Moon. *The Moon*, IAU Symposium 14, pp. 263-272. New York: Academic Press.

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Plescia, J.B., Robinson, M.S., Wagner, R. and Baldrige, R., 2016. Ranger and Apollo S-IVB spacecraft impact craters. *Planetary and Space Science*, v. 124, pp. 15-35. <https://doi.org/10.1016/j.pss.2016.01.002>

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Smith, G.M., Vrebalovich, T. and Willingham, D.E., 1966. "Eyes on the Moon". *Astronautics and Aeronautics*, v. 4, no, 3, pp. 74-83.

Vegos, C. J., Borncamp, F., Liu, A.S. *et al.*, 1968. *The Ranger IX flight path and its determination from tracking data*. JPL Technical Report 32-767, 1 November 1968.

Wagner, R.V., Nelson, D.M., Plescia, J.B. *et al.*, 2017. Coordinates of anthropogenic features on the Moon. *Icarus*, v. 283, pp.92-103. <http://dx.doi.org/10.1016/j.icarus.2016.05.011>

Whitaker, E. A., 1972. Artificial lunar impact craters: four new identifications. *Apollo 16 Preliminary Science Report*, NASA SP-315, pp. 29-39 to 29-45. Washington, D. C.: NASA.



10 April 1965: Luna 1965A

This was another attempted lunar lander essentially identical to Lunas 4 and 9. After launch from Baikonur the stage 3 engine failed and the vehicle was destroyed as it re-entered the atmosphere. The target would have been in western Oceanus Procellarum (Figure 38B).



09 May 1965: Luna 5

Luna 5 was another in the series of attempted lunar landing missions essentially identical to Lunas 4 and 9. Each flight contributed to spacecraft design and lunar flight experience. The 1474 kg (dry mass) spacecraft launched from Baikonur at 07:55 UT. A gyroscope failure resulted in a spin which was corrected, but as Luna 5 approached the Moon the retrorocket system failed and the spacecraft impacted the lunar surface at 19:10 UT on 12 May, southwest of Copernicus (Figure 31). The target area was probably in western Oceanus Procellarum, 700 km further west (Figure 38B). Ksanfomality (2018) described photographs taken at the Abastumani Astrophysical Observatory in Georgia (USSR) which show a significant change between images, interpreted to be an impact-raised dust cloud. The impact coordinates were first estimated to be 1.6° S, 25.0° W (or 26.1° W), and the dust cloud location was 1.35° S, 25.48° W. The NASA Space Science Data Coordinated Archive (NSSDCA) description of the mission also mentions an estimated location at 8.17° N, 23.43° W, as well as reflecting confusion between the spacecraft and upper stage impact locations (<https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1965-036A>).

The upper stage rocket apparently struck the Moon at 19:15 UT southeast of the crater Pitatus somewhere near 32° S, 8° W. Alternate locations sometimes reported are 31° S, 8° W, and the northern rim of Pitatus at about 28° S, 13° W, perhaps based on tracking data. Another NSSDCA location, 32° S, 8° E, reflects confusion between the old astronomical definition of east on the Moon and the post-1960 IAU definition. The first of these locations is the centre of a reported impact cloud (Figure 31C). This possible expanding cloud at the location near Pitatus was

photographed at the Rodewisch tracking station in East Germany (Anonymous, 1965). The cloud grew to about 200 by 80 km, reportedly rising about 90 km high (the basis for the latter figure is uncertain) and had fully dissipated within ten minutes. Earth-based impact observations in this period are not universally accepted as real, and this apparent dust cloud was much larger than would be expected for a simple impact. If this event was real and was caused by the rocket impact the size suggests that a substantial amount of residual propellant vapour was released and helped raise and spread the dust.

Figure 31C shows the area covered by the possible cloud, with an approximate location for the impact added at its center. Other impacts reported to have been seen from Earth are Luna 2, Luna 7 and Hiten, but no NASA spacecraft impacts were ever observed in the 1960s despite attempts to do so. More recent impacts such as that by SMART-1 and Kaguya have been recorded successfully. Figures 31D and 31E show the reported Luna 5 impact site based on spacecraft tracking. More realistically, considering the many uncertainties, Luna 5 could have struck the surface anywhere within the area of Figure 31E. Lyubimov (1967) states that some radiation measurements were made during the flight.

Anonymous, 1965. Photos of dust raised by Moon probe. *New Scientist*, v. 26, no. 449, p. 842, 24 June 1965.
Ksanfomality, L. S., 2018. Luna-5 (1965): Some Results of a Failed Mission to the Moon. *Cosmic Research*, v. 56, no. 4, pp. 276–282, July 2018, <https://doi.org/10.1134/S0010952518040020>
Lyubimov, G.P., 1967. Measurement of the Intensity of Cosmic Radiation During the Flights of Automatic Interplanetary Stations Zond-1, Zond-2, Zond-3, Luna-5, Luna-6. NASA translation no. ST-CR-IS-10655.



08 June 1965: Luna 6

Luna 6 was another in the Soviet Union's series of attempted lunar landing missions. Launch of the 1440 kg spacecraft from Baikonur was at 07:41 UT. Initial reports were that everything was functioning normally, but two days after launch the rocket engine failed to shut down at the end of a midcourse correction. This resulted in Luna 6 missing the Moon by 161 000 km and entering solar orbit. It was tracked out to a distance of 600,000 km. The lunar designation was given for its flight to and past the Moon's orbit, and for testing parts of the landing sequence including ejecting the lander and inflating the airbags. The landing target would have been in western Oceanus Procellarum (Figure 38B). Lyubimov (1967) states that some radiation measurements were made during the flight.

Lyubimov, G.P., 1967. Measurement of the Intensity of Cosmic Radiation During the Flights of Automatic Interplanetary Stations Zond-1, Zond-2, Zond-3, Luna-5, Luna-6. NASA translation no. ST-CR-IS-10655.



1965: U.S. landing site planning

Landing site planning took a back seat to technical issues and general scientific questions in the early years of the Apollo program. NASA's initial position was that any site would provide important new data. A 1962 Space Science Board meeting in Iowa (NAS-NRC 1962) briefly highlighted the obvious need to study highlands as well as maria. This began to change beginning in 1965. The Space Science Board met at Woods Hole from 20 June to 16 July of that year and compiled a list of scientific questions to be addressed by lunar exploration, repeating the Iowa opinion in the process (NAS-NRC 1966). No specific landing sites were indicated, but the Woods Hole study pointed out that effective geophysical and geochemical studies demanded several landings at sites up to 1000 kilometers apart.

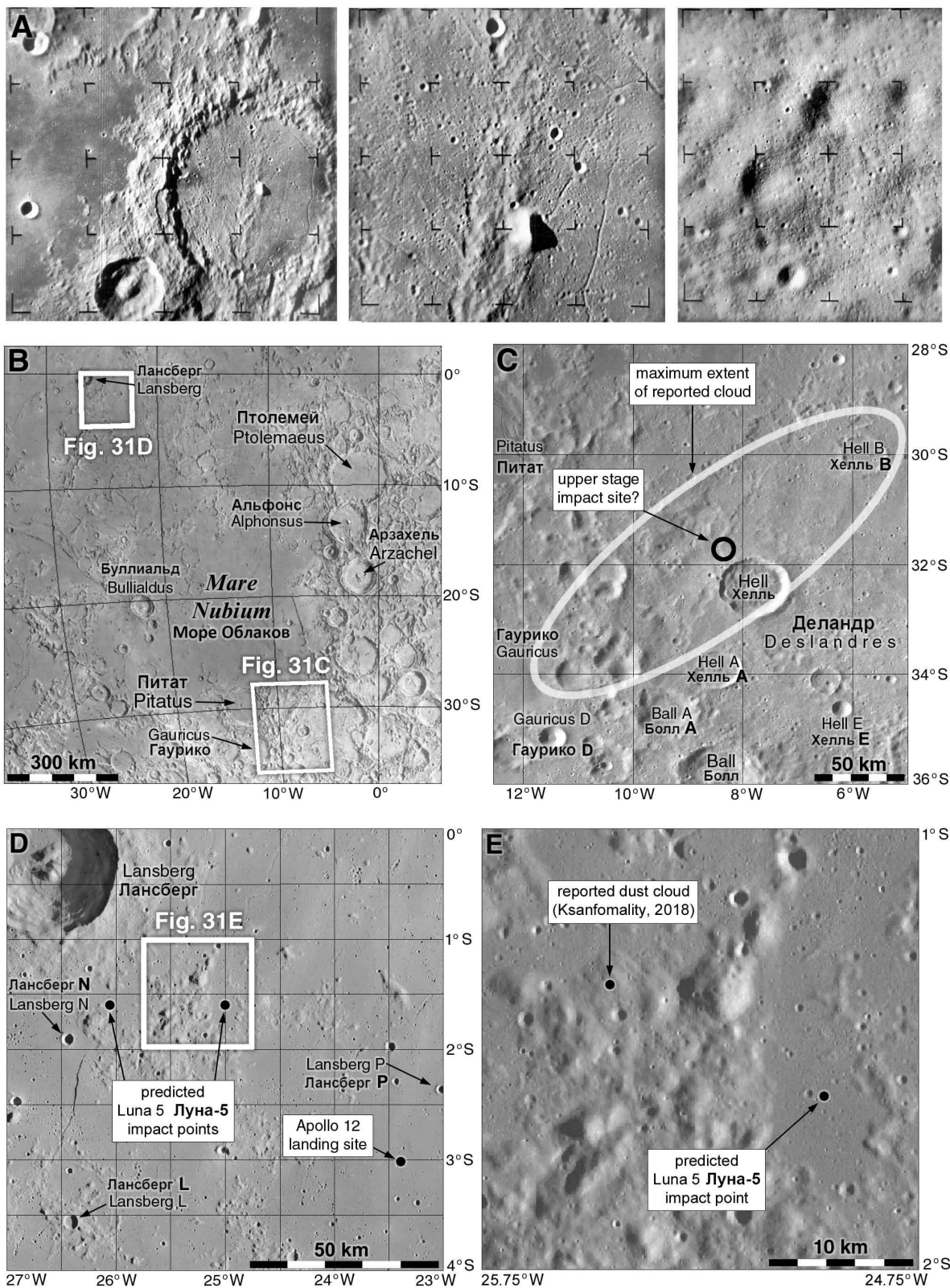


Figure 31: Ranger 9 and Luna 5. A: Representative Ranger 9 images. B: Luna 5 impact region. C: Luna 5 upper stage impact area near Pitatus. C and D: Luna 5 impact site near Lansberg. Luna 5 could have struck the surface anywhere within Figure 31E. Base images for C, D and E are LROC WAC mosaics.

At a conference on lunar exploration in Falmouth, Massachusetts immediately following the 1965 Woods Hole study, scientists stressed the need for detailed study by orbiting satellites as well as human landings (NASA 1965a). This took into account the operational limitations of Apollo and the resulting restrictions on landing sites. The scientists urged development of surface and flying vehicles to increase the range of exploration from a specific site, assuming that landings would eventually be extended beyond the Apollo zone to higher latitudes, rugged highlands and large craters. At this time, better information on the lunar surface was needed before the scientific merits of specific sites could be weighed.

Presentations at Falmouth included Harrison Schmitt's example of EVA planning on high resolution Ranger images (Figure 27B) and the long traverses illustrated in Figure 32A (NASA 1965a; JPL 1966). These examples of possible traverses showed how up to six successive Apollo missions could employ reusable long-range vehicles to establish geological relationships over large areas. The indicated points were described but the routes were not illustrated in the report and are conjectural.

Ranger photographs encouraged NASA with their generally benign-appearing views of lunar topography, though the fractures in the floor of Alphonsus worried some geologists. MSC's Space Environment Division felt that Ranger images alone were inadequate to certify lunar landing sites. Orbiters would be more efficient than multiple Ranger-style impacts, and landers were needed to provide data on the physical characteristics of the surface. MSC offered advice to the Surveyor project staff at the Jet Propulsion Laboratory concerning sites of maximum use to Apollo. MSC also advised Langley's Lunar Orbiter project on the use of its high-resolution cameras to validate sites for the lunar landing mission.

The Ranger scientists had been irritated by pressure from Apollo officials to direct Rangers 8 and 9 to bland sites suitable for human landings. NASA's Homer Newell, hoping to avoid similar problems with Surveyor and Lunar Orbiter, established the ad hoc Surveyor/Orbiter Utilization Committee on 22 June. On 6 August George Mueller established the Apollo Site Selection Board in the Office of Manned Space Flight, to evaluate and select landing sites (Compton, 1989.)

A variety of plans for future lunar operations were being developed at about this time, including thoughts about programs after Apollo itself. Although President Kennedy had called for just one landing, few people involved in space planning expected that lunar exploration would end after one flight. The vast expense seemed to demand a reasonable period of exploration if only to obtain a sufficient return on the investment. A 1965 report from NASA's Office of Space Science and Applications (OSSA) outlined such a plan, illustrating a possible exploration sequence rather than a specific proposal (NASA 1965b). The report included a suggestion that the micrometeoroid hazard in lunar orbit be investigated by a 'Lunar Pegasus' orbiter equipped with large extendable panels.

The OSSA plan foresaw a small number of Apollo landings followed by a more capable Apollo Extension System (AES), using advanced hardware and capabilities to increase science return (Figure 32B, Table 12). Orbital photography flights with ejected robotic landing probes were added to the sequence of astronaut landings. Both soft- and hard-landing probes were to be used. The exploration schemes illustrated in Figure 33 were based on a model involving intensive exploration of one site with multiple Saturn V launches. Suitable sites would be those in which many different types of feature of geological interest were found within a small area, accessible to the types of rover considered here. Figure 32C shows fifteen areas with the desired characteristics, adapted from Figure 9 of de Fries (1967).

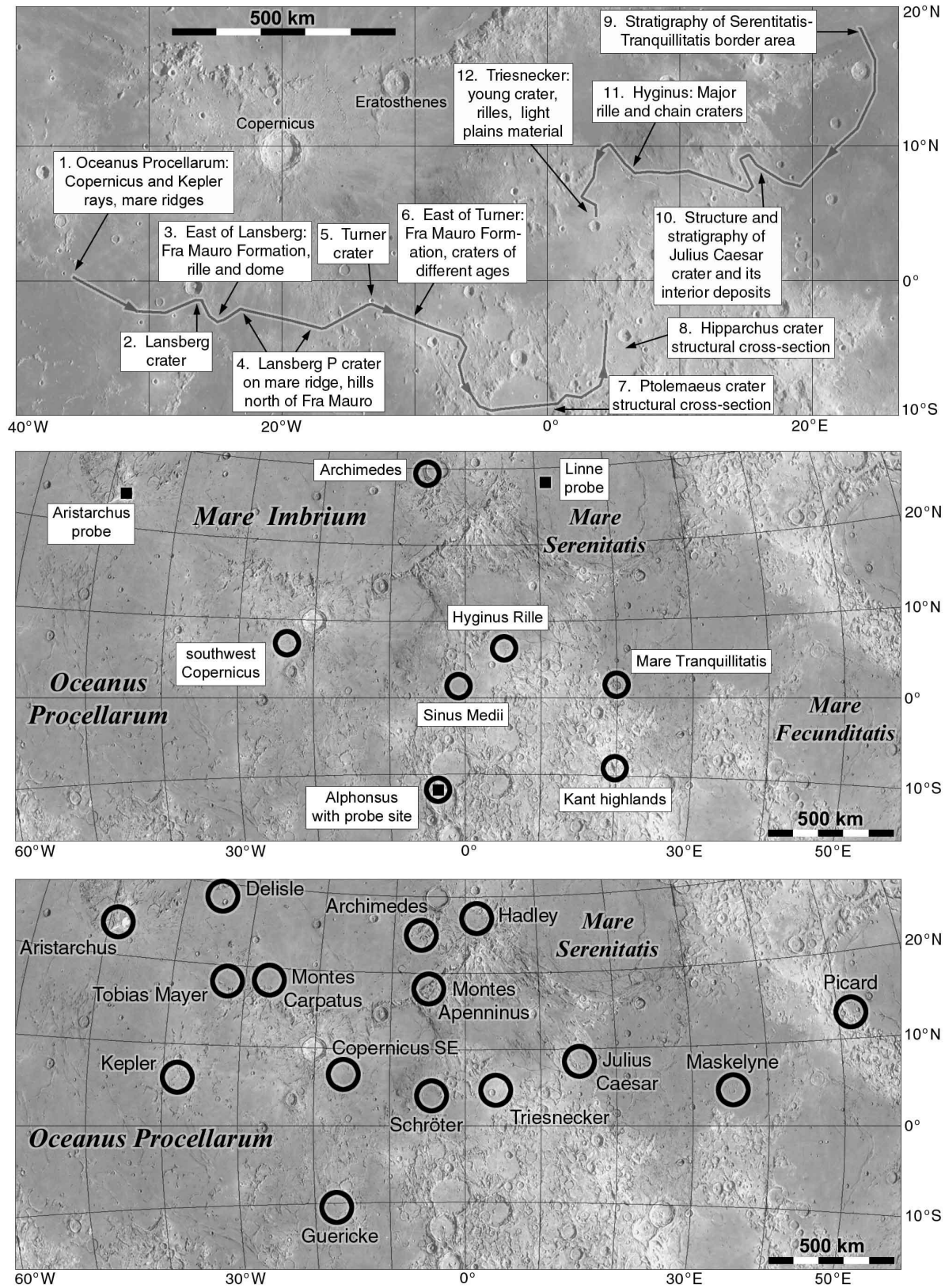


Figure 32. Apollo planning. A: Traverses described at the Falmouth meeting. B: OSA lunar exploration sites. C: Areas suitable for Apollo rover missions such as those illustrated in Figure 33, from de Fries (1967).

Table 12. OSSA Illustrative Lunar Flight Mission Assignment Plan, 1965.

Mission	Landing Site	Major Scientific Activities	Most Significant Scientific Return
1st Apollo	Sinus Medii, 2° N, 1° W	Samples, instrument package, geological observations, photography	First unambiguous knowledge of lunar surface, age estimate, lunar surface processes, internal structure, field measurements.
2nd Apollo	Mare Tranquillitatis, 2° N, 20° E	As for first landing	Study of a new area, improved geophysical (fields, internal structure) measurements from simultaneous observation with first mission instruments.
Orbiter, low inclination (10°)	Probes: Alphonsus, farside, candidate 3rd landing sites	Monitoring remote sensing instruments, probes.	Repeat coverage of equatorial belt under varying lighting conditions, first surface data from farside, possible volcanic gas analysis, gravity profiles.
3rd Apollo	Return to a previous site, or new mare site, or a highland or crater interior site.	As for first landing	Confirm previous results, or study a new type of surface, with age estimate of older material and instruments in different geophysical environment.
1st AES	Hyginus Rille, 7° N, 5° E	Mapping from rover, samples, drilling, instrument package, <i>in situ</i> sample analysis.	Study of a larger area from rover (200 km ²), ground truth support for orbital surveys, samples from depth (2 to 3 m) using drill, possibly including bedrock, deep seismic data, heat flow data.
Orbiter, 30° – 40° inclination	Probes: Aristarchus, Linne, farside, future landing sites.	Monitoring remote sensing instruments, probes.	Wide sensor coverage from orbit, possible volcanic gas analysis, gravity profiles.
2nd AES	Interior crater – Alphonsus, 12° S, 4° W	As for first AES	Similar to first AES but in very different area with possible volcanic gas emissions.
Orbiter, polar	Probes: farside, polar regions, future landing sites	Monitoring remote sensing instruments, probes.	As for previous orbiter, with global coverage, and possible composition data from perpetually shadowed areas.
3rd AES	SW Archimedes 29° N, 6° W	As for first AES, and deploy radio telescope	Similar to AES flights 1 and 2, with first radio astronomy experiments.
4th AES	Highlands N of Kant 9° S, 20° E	As for 3rd AES, and deploy optical telescope	Similar to AES flight 3, with first optical astronomy studies. Telescopes operated remotely after crew departure.
Orbiter, polar	Probes: concentrated farside coverage	Monitoring remote sensing instruments, probes.	As for previous polar orbiter.
5th AES	Farside site	As for 3rd AES	As for 3rd AES
1st advanced mission, extended stay time.	SW Copernicus 7° N, 23° W, or old site near equator (Sonett report, page 26)	Simultaneous surface and low inclination orbital operations, long distance rover.	Ground check of orbital data, radio and optical astronomy (1 m optical telescope), evaluation of long life laboratories and observatories, advanced measurements and surveys.

Compton, W. D., 1989. *Where no man has gone before: a history of Apollo lunar exploration missions*. NASA SP-4214. Washington, D.C.: National Aeronautics and Space Administration.

de Fries, P. J., 1967. Lunar Surface Locomotion, *Advances in Space Science and Technology*, v. 9, pp. 275-454.

JPL, 1966. *Ranger VIII and IX. Part II. Experimenters' analyses and interpretations*, JPL Tech. Rep. 32-800.

Pasadena: Jet Propulsion Laboratory.

NASA 1965a. *Summer Conference on Lunar Exploration and Science, Falmouth, Massachusetts, July 19- 31, 1965*, NASA SP-88. Washington, D.C.: National Aeronautics and Space Administration.

NASA 1965b. *Technical Plan for the Scientific Exploration and Utilization of the Moon. Manned Space Science Program, June 1965*. Washington, D.C.: National Aeronautics and Space Administration.

NAS-NRC, 1962. A review of space research, report of the summer study conducted under the auspices of the Space Science Board at the State University of Iowa, June 17-Aug. 10, 1962, National Academy of Sciences-National Research Council Publication 1079 (Washington, 1962).

NAS-NRC, 1966. Space research: directions for the future, report of a study by the Space Science Board, Woods Hole, Mass., 1965. Publication 1402. Washington, D. C: National Academy of Sciences-National Research Council.



1965: Geological Traverse Planning

Apollo planning extended beyond the selection of safe landing sites towards considering true geological exploration during the mid-1960s. The first geological map sheet produced by the U.S. Geological Survey at 1:1 000 000 scale included the craters Kepler and Encke, so this area was used for early exploration studies. Numerous variations on plans for mobile surface missions were considered between 1964 and 1966 at NASA centers and aerospace companies. Several examples are shown in Figure 33. Most of them required a large pressurized rover able to carry two astronauts and landed with other supplies before the crew arrived.

Figure 33 shows six different conjectural missions in the Kepler region. They were based on the geology depicted by Hackman (1962) but are plotted here on a modern map (LROC wide-angle camera mosaics).

Figure 33A illustrates a plan described by Lassen and Park (1964). It shows routes and features for detailed study by a remote-controlled rover supporting human explorers. Figure 33B is a plan developed by Northrop Aviation. The first traverse would visit various sites of scientific interest before returning to the base. If time and fuel permitted, a second traverse could also be attempted (Lee, 1966). The jagged outlines result from a grid-based route planning strategy. Figure 33C is a mission design by Carr and Romano (1965) which identifies science stations (dots) along two traverses, where the crew could examine craters, mountains and fractures. Figure 33D is from Schaefer and Yarbrough (1964), illustrating a new concept. One traverse is driven during lunar daylight, but a second loop would be driven during the lunar night, using Earthlight or artificial light as necessary.

Figures 33E and 33F are taken from Evans (1964), Figures 7 and 9 respectively. They show two different concepts for lunar mobility. ALSS (Apollo Logistic Support System) involved landing a rover and a crew on separate flights. The rover would be capable of operating by remote control or with a crew. The second traverse would use a second rover and crew, requiring four landings at this site. LESA (Lunar Exploration System for Apollo) involved three flights, one to deliver cargo including a rover, one to bring the crew, and a third to take the crew home. Various sampling goals over a 90 day mission are indicated. Large scale explorations like these, analogous to many Antarctic expeditions, went far beyond the limited goals officially endorsed for NASA.

Carr, J. H. and Romano, S., 1965. A mobile lunar laboratory system. *Advances in the Astronautical Sciences*, v. 20, part 2, pp. 559-614.

Evans, T. C., 1964. Extended lunar exploration. *Advances in the Astronautical Sciences*, v. 18, pp. 480-500.

Hackman, R. J., 1962. *Geologic map and sections of the Kepler region of the Moon*, Misc. Inv. Map I-355, U. S. Geological Survey.

Lassen, H. A. and Park, R. A., 1964. The role of unmanned systems in lunar exploration. *Astronautics and Aeronautics*, v. 2, no. 3, March 1964, pp. 12-19.

Lee, M., 1966. Vehicles for lunar exploration. *Science Journal*, August 1966, pp. 3-9.

Schaefer, H. and Yarbrough, L. S., 1964. Apollo logistic support system. *Advances in the Astronautical Sciences*, v. 18, pp. 532-569.

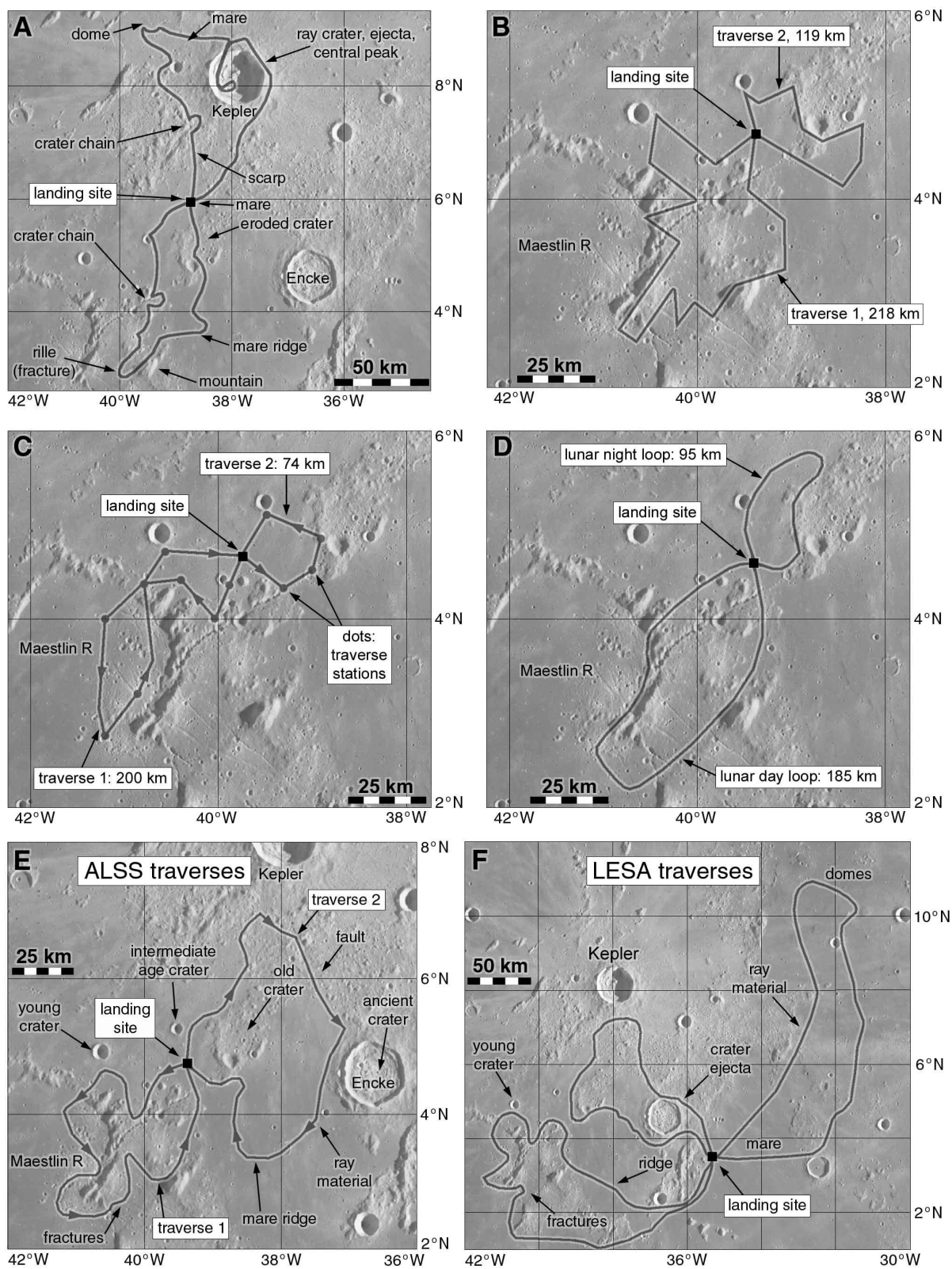


Figure 33: Early geological traverse plans. A: from Lassen and Park (1964). B: from Lee (1966). C: from Carr and Romano (1965). D: from Schaefer and Yarbrough (1964). E, F: from Evans (1964). Base image: LROC wide angle mosaic with coordinates slightly adjusted to match those in use at the time.



1965: Bellcomm defines the Apollo Zone

Bellcomm, Inc. was established by American Telephone and Telegraph Co. and Western Electric Co. in early 1962 to provide technical support to NASA for the Apollo program, including the site selection process. It was closed down on 1 April 1972 after the last Apollo site selection work was completed.

The notion of an Apollo area of interest, a region of the Moon's earthside which was easiest and safest to reach and return from, was developed as early as 1962 (Figure 16A). Bellcomm performed detailed trajectory studies for numerous possible mission plans and in 1965 defined a more formal Apollo Zone, extending now from 45° E to 45° W and 5° N to 5° S. There was some variation in the way the Apollo zone was defined in published documents, partly because of the informal usage of earlier reports and partly because it was not intended to be more than a planning guide. Latitudinal extents of 40°, 46° and 50° in each direction were also mentioned.

In practice, for any given mission date and orbital inclination there would be an operationally defined accessible area on the Moon, in which the landing site would have to lie (Cappellari, 1972). For early Apollo missions this took the form of a 'bow tie' shape, as shown in Figure 34A for Apollo 11. Later missions could use greater orbital inclinations and had wider accessible areas (Figure 34A). Here too the shape depends on various assumptions and might differ significantly from that shown here. For instance, the shape shown in Figure 34A does not include either Gassendi, Tycho or the Marius Hills, all long considered favourites for a later landing. At the first meeting of the Apollo Site Selection Board in March 1966 another version of the 'bow tie' shape was illustrated (Figure 34B), this time for an anticipated first landing in 1968.

Cappellari Jr., J. O., 1972. Where on the Moon? An Apollo Systems Engineering Problem. *The Bell System Technical Journal*, vol. 51, no. 5, pp. 955-1127.



1965-1966 Surveyor Site Planning

Surveyor landing site planning began in 1964 with the selection of a few scientifically interesting targets (Figure 21). As launch approached the demands of the Apollo program began to encroach on Surveyor. The U. S. Geological Survey was asked to compile a list of suitable targets, and its internal report (USGS, 1965) describing 74 sites is summarized here. The authors were not identified in the report, but according to Wilhelms (1993) they were J. McCauley, E. Morris, L. Rowan, J. O'Conner and H. Holt.

These sites were relatively obstacle-free circular areas within 10° of the equator. Targeting accuracy was difficult to assess without flight experience, so the sites included circles of three different sizes to reflect different assumptions. There were 74 sites in all, 37 circles of 25 km radius, 28 circles of 50 km radius and 9 circles of 100 km radius (Figure 35, Table 13). Smaller circles tend to be nested in larger ones, not always concentrically if obstacles interfered with placement, but many others could be placed where larger circles could not fit. A few of these sites became actual Surveyor targets. Surveyor 1 landed near site 14-25, Surveyor 3 at site 24-25, and Surveyor 6 at site 33-25.

Table 13 lists all 74 sites described in the USGS report. The site numbers indicate the radius of the circular site, 25, 50 or 100 km. They are listed from west to east for each size range. The terrain evaluation indicates estimated suitability for a safe landing, based on telescopic data. In general an A ranking means the site shows no visible obstacles or rays, B means that the area appears smooth but rays are present, and C means that small craters or ridges are visible.

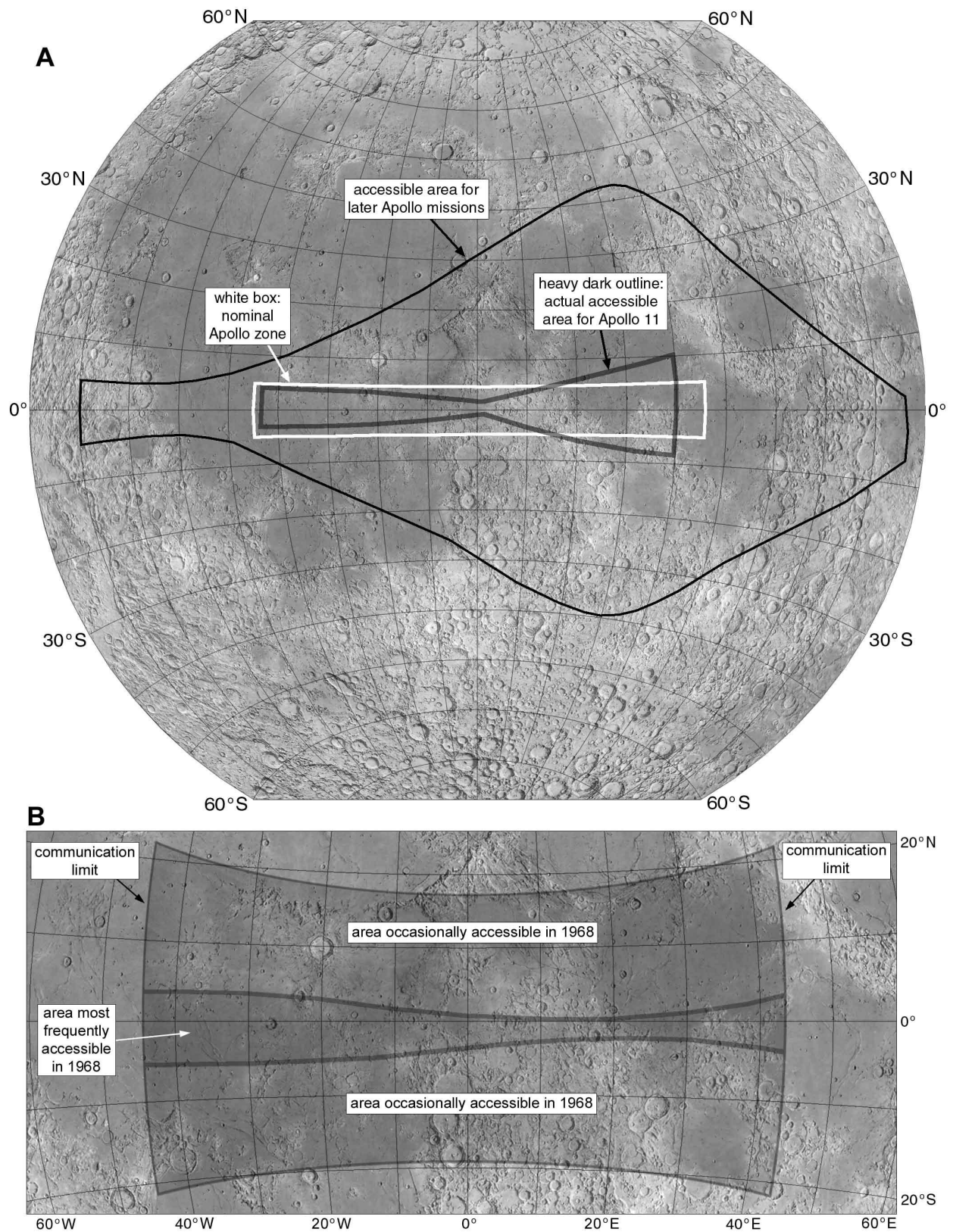


Figure 34: Apollo mission accessible areas. A: Bellcomm's Apollo Zone and accessible areas for Apollo, 1965. B: Apollo Site Selection Board accessible areas, 1966.

The scientific evaluation is an estimate of the value of knowledge to be gained at that site. An A ranking was given to sites with interesting surface materials (floors of Grimaldi and Ptolemaeus, sites 1-25 and 32-25), possible views of rilles or highlands (e.g. Julius Caesar, site 35-25) or unusual features such as Reiner Gamma, a very bright spot in Oceanus Procellarum (site 3-50). B sites are fairly typical mare surfaces, and C sites are bland.

A reduced and revised version of this list was prepared only a month later (Figure 36, Table 14). The Surveyor/Orbiter Utilization Committee (SOUC) began work on 20 July 1965, evaluating landing sites and planning orbital observations. SOUC recommended that early Lunar Orbiter missions give priority to Apollo site certification, postponing a scientifically desirable global survey to later missions after Apollo needs were satisfied (Byers 1977).

For Surveyor, 24 circular sites with 50 km radius were proposed by JPL and USGS on 29 July 1965, and 20 more 25 km circles were added in August 1965 (Table 14, white circles in Figure 36). The Mission A (Surveyor 1) site, number 9-50, was chosen to be in the Apollo zone at a longitude permitting a near-vertical descent, and in the smoothest available area. Mission B (Surveyor 2) had similar criteria except that the descent angle could be as large as 25°. It was targeted to site 21-50 (Sinus Medii). The descent angle was called the 'unbraked impact angle', the angle between the approach before braking began and the local vertical, equal to zero for a vertical approach. Surveyor could accommodate angles as high as 45°, permitting landings as far east as Mare Tranquillitatis.

Apollo managers required Surveyor landings in eastern and western mare areas and in Sinus Medii before any more interesting science sites were targeted. SOUC met again on 15 December 1966 to plan later landings, using a recently prepared list of 40 sites with 30 km radius (Filice *et al.*, 1967), all in or west of the Apollo zone (Table 15, black circles in Figure 36).

Surveyor managers at JPL resisted having their science goals subordinated to those of Apollo. SOUC approved 14 of the proposed sites for future planning (12 are shown as black triangles on Figure 36). Surveyor staff complied reluctantly, fearing that in some cases less suitable sites would be favoured to appease Apollo managers. JPL agreed to target the first Surveyor according to SOUC wishes, but if they had any trouble they made it clear they would demand that the next mission be sent to a better location.

The strategy in late 1966 for later landings would have put Surveyor 3 in Sinus Medii and Surveyor 4 at the site actually used for Surveyor 3. Surveyor 5 would be targeted for a highland basin or other science target because Mare Tranquillitatis was not reachable at the expected launch date. Surveyor 6 would go to Mare Tranquillitatis and Surveyor 7 would be free to go to any other science site. The targets for Surveyors 3 and 4 were later reversed, and when Surveyor 4 was lost the sequence had to be changed again.

Tables 14 and 15 list the two groups of possible Surveyor sites considered in 1965 and 1966 (Filice *et al.*, 1967). The 1965 site numbers indicate the circle size (last two digits, 25 or 50 km radius), and distinguish the highland and science sites with prefixes H and S. The 1966 sites are identified by their latitudes and longitudes rounded to the nearest degree. Most of the 1966 highland or highland basin sites were not plotted on the map accompanying the report, but have been added to Figure 36. In Tables 14 and 15 the coordinates are given longitude first, the reverse of the format used everywhere else, to match the original sources and for consistency with the site designation codes in Table 15.

Byers, B. K., 1977. *Destination Moon: A History of the Lunar Orbiter Program*, NASA TM X-3487 (Washington DC).

Filice, A.L., Thornton, T.H. and Willingham, D.E., 1967. *Surveyor landing site selection*. Surveyor project document 602-20. Pasadena: Jet Propulsion Laboratory.

Wilhelms D. E., 1993. *To a Rocky Moon: a geologist's history of lunar exploration*. Tucson: University of Arizona Press.



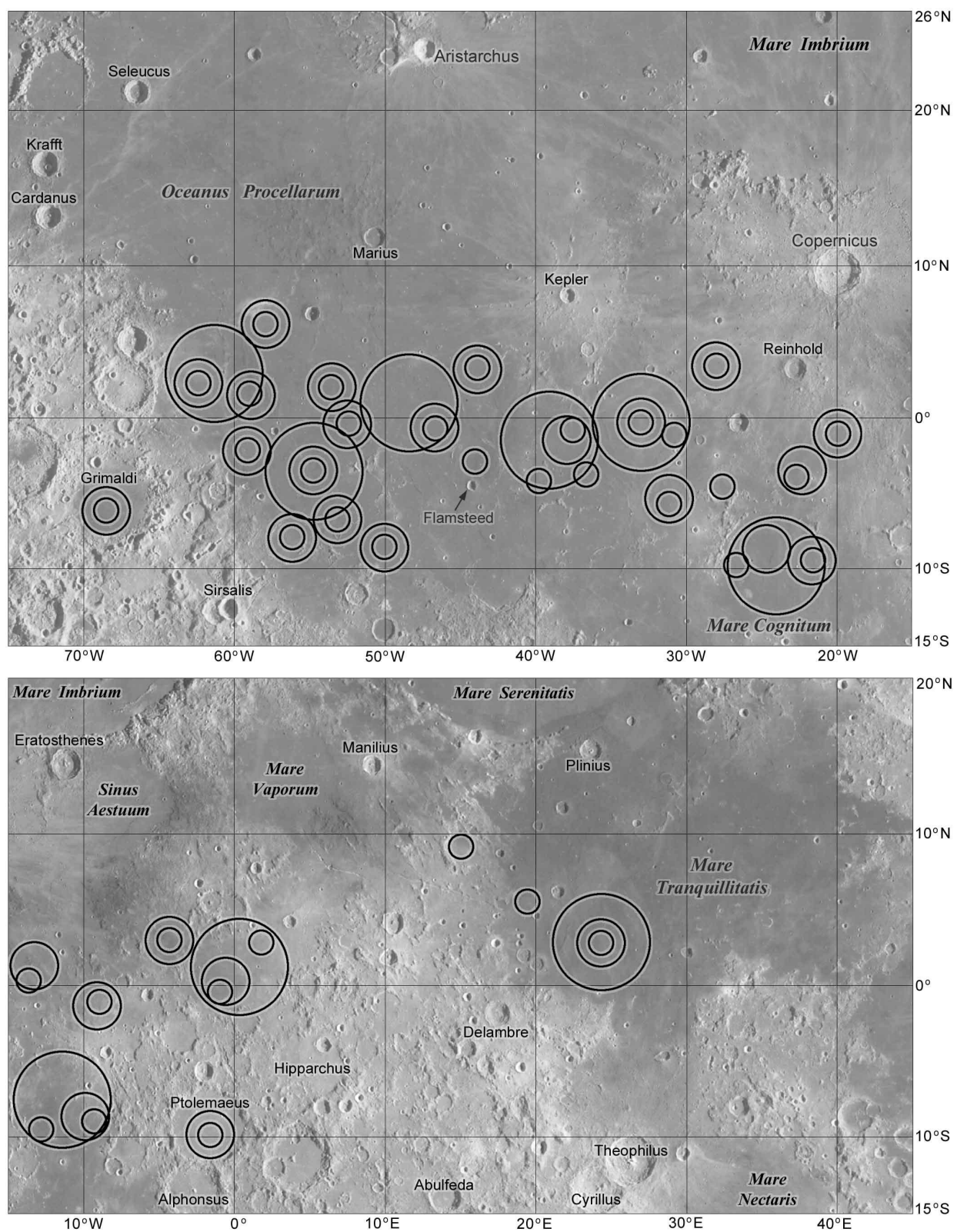


Figure 35: Surveyor sites listed by USGS, July 1965, from Table 13. The base map is an LROC wide angle mosaic. Mercator Projection with coordinates slightly adjusted to match those in use at the time. For scale, 10° of latitude or along the equator spans 300 km.

Table 13. Surveyor landing sites suggested by USGS in July 1965.

Site Number	Location	Terrain Evaluation	Scientific Evaluation	Site Number	Location	Terrain Evaluation	Scientific Evaluation
1-25	6° 10' S, 68° 30' W	A-	A	1-50	6° 10' S, 68° 30' W	B	A
2-25	2° 10' N, 62° 35' W	B	B-	2-50	2° 10' N, 62° 35' W	B	B-
3-25	5° 35' N, 59° 15' W	B	B+	3-50	5° 40' N, 59° 15' W	B	A
4-25	1° 05' N, 59° 10' W	B	B	4-50	1° 05' N, 59° 10' W	B-	B
5-25	2° 20' S, 59° 10' W	A	B+	5-50	2° 20' S, 59° 10' W	B+	B+
6-25	3° 20' S, 56° 00' W	A	B+	6-50	3° 40' S, 56° 05' W	B+	B+
7-25	8° 15' S, 56° 45' W	A-	B+	7-50	8° 00' S, 56° 00' W	B+	B+
8-25	1° 40' N, 53° 30' W	B	C	8-50	1° 42' N, 53° 30' W	B	C
9-25	6° 25' S, 53° 00' W	A	B+	9-50	6° 20' S, 53° 25' W	B+	B
10-25	1° 30' S, 52° 15' W	A	B	10-50	1° 05' S, 52° 25' W	B+	B
11-25	8° 00' S, 50° 00' W	A	B	11-50	8° 00' S, 50° 00' W	B+	B
12-25	0° 55' S, 46° 45' W	B+	C+	12-50	0° 55' S, 46° 45' W	B-	C+
13-25	3° 25' N, 44° 10' W	B-	B-	13-50	3° 25' N, 44° 10' W	B-	B-
14-25	3° 15' S, 43° 50' W	B+	B+	14-50	1° 40' S, 38° 10' W	C+	C+
15-25	4° 30' S, 39° 45' W	B	C+	15-50	0° 10' S, 33° 30' W	B-	B
16-25	1° 00' S, 37° 40' W	C+	C+	16-50	5° 20' S, 31° 25' W	B-	C+
17-25	4° 00' S, 36° 50' W	B+	C+	17-50	3° 00' N, 28° 20' W	C	B+
18-25	0° 10' S, 33° 30' W	B	B	18-50	8° 10' S, 25° 00' W	B	B+
19-25	1° 05' S, 31° 25' W	B+	C+	19-50	3° 45' S, 22° 45' W	B-	B-
20-25	5° 50' S, 31° 25' W	B	C+	20-50	8° 50' S, 21° 40' W	C	B
21-25	3° 00' N, 28° 20' W	C+	B	21-50	1° 20' S, 19° 50' W	C	B+
22-25	4° 30' S, 27° 45' W	C-	B	22-50	1° 00' N, 13° 05' W	C	A-
23-25	9° 40' S, 27° 00' W	B+	B+	23-50	9° 15' S, 10° 10' W	B+	B
24-25	4° 10' S, 23° 05' W	B	C+	24-50	1° 25' S, 9° 20' W	B	B-
25-25	8° 55' S, 21° 40' W	B	C+	25-50	2° 35' N, 4° 25' W	B	B
26-25	1° 20' S, 19° 50' W	C+	B+	26-50	9° 40' S, 1° 50' W	C	A-
27-25	0° 10' N, 13° 30' W	C+	B	27-50	0° 00' N, 0° 40' W	B+	B
28-25	9° 50' S, 12° 50' W	B+	B	28-50	2° 40' N, 24° 35' E	B	A-
29-25	9° 15' S, 9° 35' W	A	B	1-100	2° 50' N, 61° 30' W	B	B+
30-25	1° 15' S, 9° 05' W	B+	C+	2-100	3° 45' S, 55° 10' W	B+	B+
31-25	2° 35' N, 4° 25' W	B	B	3-100	0° 50' N, 48° 15' W	B	C+
32-25	9° 40' S, 1° 50' W	C+	A-	4-100	1° 55' S, 39° 00' W	C	B
33-25	0° 25' S, 1° 20' W	A	B	5-100	0° 10' S, 33° 30' W	C	C+
34-25	1° 15' N, 2° 30' E	A	B	6-100	9° 40' S, 24° 25' W	B	C+
35-25	8° 55' N, 15° 00' E	B+	A-	7-100	7° 35' S, 11° 50' W	C-	B
36-25	5° 25' N, 19° 05' E	B+	A-	8-100	1° 00' N, 0° 05' E	B+	B
37-25	2° 40' N, 24° 35' E	B	B+	9-100	2° 40' N, 24° 35' E	B	B+

Note: the second digit in the site number is its diameter in kilometres.

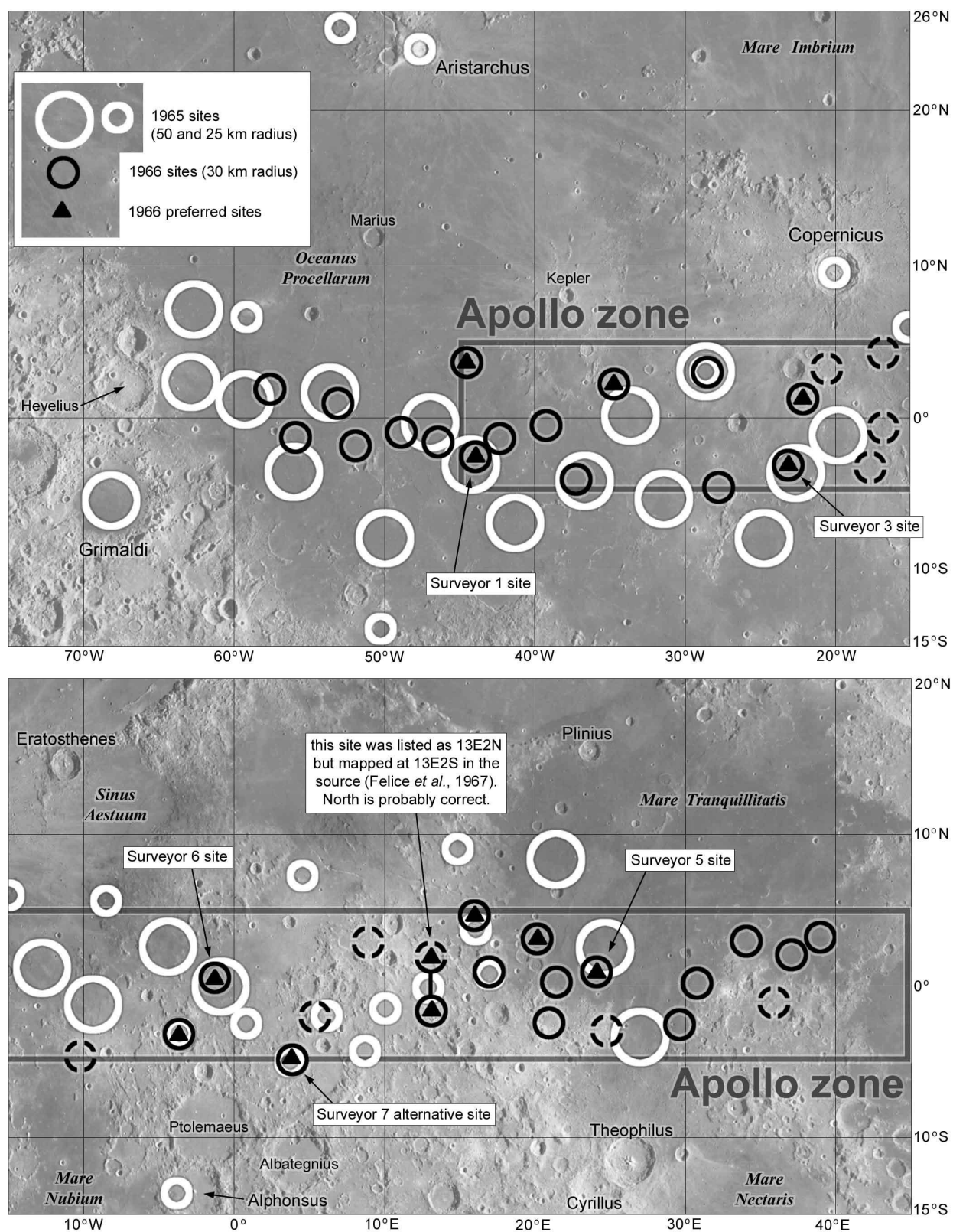


Figure 36: SOUC Surveyor sites from Tables 14 and 15 (Filice *et al.*, 1967). The base map is an LROC wide angle mosaic. Mercator Projection with coordinates slightly adjusted to match those in use at the time. For scale, 10° of latitude or along the equator spans 300 km.

Table 14: Proposed Surveyor landing sites, JPL and USGS, August 1965. (50 and 25 km radius sites)					Table 15: Surveyor equatorial sites, October 1966. (30 km radius sites)		
terrain type	site number	location	Rating*		terrain type	site number	location
			terrain	scientific interest			
mare	1-50	68° 30' W, 6° 10' S	A	A	mare	58W-2N	57° 30' W, 1° 40' N
	2-50	62° 35' W, 2° 10' N	C	C		56W-1S	55° 55' W, 1° 25' S
	3-50	62° 30' W, 7° 00' N	B	C		53W-1N	53° 05' W, 0° 45' N
	4-50	57° 40' W, 1° 00' N	B	B		52W-2S	52° 00' W, 1° 55' S
	5-50	56° 05' W, 3° 40' S	A	B		49W-1S	48° 55' W, 1° 00' S
	6-50	53° 30' W, 1° 42' N	A	C		46W-1S	46° 20' W, 1° 25' S
	7-50	50° 00' W, 8° 00' S	A	B		44W-3N	43° 55' W, 3° 20' N
	8-50	46° 45' W, 0° 55' S	B	C		SC-1	43° 50' W, 2° 20' S
	9-50	43° 50' W, 3° 15' S	B	A		42W-2S	41° 55' W, 1° 30' S
	10-50	41° 10' W, 7° 00' S	B	C		39W-1S	39° 10' W, 0° 30' S
	11-50	36° 50' W, 4° 00' S	B	C		37W-4S	37° 00' W, 3° 50' S
	12-50	33° 30' W, 0° 10' S	C	B		35W-2N	34° 55' W, 2° 25' N
	13-50	31° 25' W, 5° 20' S	C	C		28W-3N	28° 20' W, 3° 05' N
	14-50	28° 20' W, 3° 00' N	D	B		28W-5S	27° 40' W, 4° 30' S
	15-50	24° 45' W, 8° 00' S	B	B		23W-3S	23° 10' W, 3° 20' S
	16-50	22° 45' W, 3° 45' S	C	C		1W-1N	0° 50' W, 0° 35' N
	17-50	19° 50' W, 1° 20' S	D	B		20E-3N	20° 15' E, 3° 20' N
	18-50	13° 05' W, 1° 00' N	D	A		22E-0N	21° 30' E, 0° 20' N
	19-50	9° 20' W, 1° 25' S	C	B		24E-1N	24° 00' E, 1° 00' N
	20-50	4° 25' W, 2° 35' N	C	B		30E-2S	29° 40' E, 2° 15' S
	21-50	0° 40' W, 0° 00' N	A	B		31E-0N	30° 55' E, 0° 25' N
	22-50	21° 30' E, 8° 25' N	B	B		34E-3N	34° 00' E, 2° 45' N
	23-50	24° 35' E, 2° 40' N	C	A		37E-2N	36° 55' E, 2° 05' N
	24-50	27° 00' E, 3° 20' S	D	C		39E-3N	39° 00' E, 2° 45' N
highland	H-1-25	3° 40' W, 3° 10' S	D	B	highland basin	4W-3S	3° 40' W, 3° 20' S
	H-2-25	0° 50' E, 2° 25' S	C	B		4E-5S	4° 05' E, 4° 45' S
	H-3-25	3° 45' E, 5° 00' S	D	B		16E-5N	16° 10' E, 4° 30' N
	H-4-25	8° 40' E, 4° 20' S	D	B	highland	22W-1N	22° 05' W, 1° 10' N
	H-5-25	10° 10' E, 1° 30' S	D	B		21W-3N	20° 40' W, 3° 10' N
	H-6-25	12° 50' E, 0° 00' N	C	A		18W-3S	17° 30' W, 3° 20' S
	H-7-25	16° 00' E, 4° 00' N	C	A		17W-1S	16° 40' W, 0° 40' S
science	S-1-25	47° 20' W, 23° 40' N	D	B		17W-4N	17° 00' W, 4° 25' N
	S-2-25	52° 40' W, 26° 40' N	B	B		10W-5S	10° 20' W, 4° 30' S
	S-3-25	59° 20' W, 6° 30' N	C	B		6E-2S	5° 30' E, 2° 10' S
	S-4-25	50° 00' W, 13° 45' S	A	A		9E-3N	8° 55' E, 3° 10' N
	S-5-25	28° 25' W, 3° 00' N	D	C		13E-2N	13° 25' E, 1° 30' N
	S-6-25	20° 00' W, 9° 50' N	D	A		17E-1N	17° 15' E, 0° 55' N
	S-7-25	15° 00' W, 5° 45' N	C	A		21E-2S	21° 00' E, 2° 00' S
	S-8-25	8° 20' W, 5° 40' N	D	B		24E-3S	23° 35' E, 2° 55' S
	S-9-25	4° 00' W, 13° 40' S	D	B		36E-1S	35° 50' E, 0° 50' S
	S-10-25	5° 00' E, 7° 00' N	D	B	*ratings for the 1965 sites (Table 11) are on a four point scale in which A is best, D is worst.		
	S-11-25	6° 10' E, 2° 00' N	D	B			
	S-12-25	15° 00' E, 8° 55' N	B	A			
	S-13-25	17° 00' E, 1° 00' N	C	B			

18 July 1965: Zond 3

Zond 3 was initially designed to fly past Mars during the 1964 launch window as a companion to Zond 2. Technical problems caused the Mars opportunity to be missed, and the spacecraft was instead launched into deep space as an engineering test. The 960 kg Zond 3, 3.5 m long and 4 m across its solar panels, was launched from Baikonur at 14:38 UT into a parking orbit, then placed on a lunar flyby trajectory. The spacecraft was equipped with a film camera system and scanner more advanced than that of Luna 3, a magnetometer, ultraviolet and infrared spectrographs, radiation sensors, a radio telescope and a micrometeoroid detector. It also carried an experimental ion engine.

The lunar flyby occurred on 20 July, 33 hours after launch at a closest approach distance of 9200 km. The images covered much of the region not seen by Luna 3, in effect fulfilling the missions of Lunas 1960A and 1960B. Each of the 25 scanned frames had 1100 by 860 pixels. Good quality images were taken of the lunar farside from distances between 11570 and 9960 km over a period of 68 minutes, as well as 3 ultraviolet images. The images were transmitted from a distance of 2.2 million km, and later from 31.5 million km to demonstrate the ability of the communications system at planetary distances. After the flyby, Zond 3 continued into a heliocentric orbit.

The new images (Figures 37A, 37B) revealed the large multi-ringed basins Hertzsprung (initially named Kibal'chich) and Korolev, and gigantic crater chains which the Soviets named after their rocket research institutes (GDL, GIRD, RNII). GDL was the Gas Dynamics Laboratory (Газодинамическая лаборатория), GIRD was the Group for the Study of Reactive Motion (Группа изучения реактивного движения) and RNII was the Reactive Scientific Research Institute (Реактивный научно-исследовательский институт). RNII was formed by combining GDL and GIRD in 1933. Korolev's identity as the architect of the Soviet Union's space program had been concealed prior to his death on 14 January 1966, but when maps made from Zond 3 images (Figure 38A) were produced in the following year his name appeared on them. The names shown in Figure 37C were not recognized by the IAU at the time, but some became official in 1970, though most were applied to different features.

Figure 37 illustrates Zond 3 images. Figure 37A shows part of Oceanus Procellarum at right and Mare Orientale left of centre. The small dark spot southwest of Orientale was informally named Mare Pacificus (More Mirnoe) in Russian maps of the time. It was later recognized as a central vent volcanic plume deposit similar to some seen on Jupiter's moon Io (Head *et al.*, 1997). Figure 37B is a mosaic of the farside coverage. The jagged boundary at lower left is formed by a photometric target which covers different areas of the lunar surface in each frame (as shown at lower left in Figure 37B) but has been omitted in the mosaic. Zond 3 images hint at South Pole-Aitken basin ring structures, though this seems not to have been noted at the time. The original images were provided courtesy of the Sternberg State Astronomical Institute, and the mosaic (Figure 37B) is by P. Stooke.

Figure 38A reproduces the equatorial section of the first complete map of the Moon, compiled under the direction of Yuri N. Lipsky and incorporating Luna 3 and Zond 3 data (*Polnaya Karta Luny*, Sternberg State Astronomical Institute, 1967). The images themselves appeared in Lipsky (1965a; b).

Head, J. W., Wilson, L. and Weitz, C. M., 1997. The dark ring in southwestern lunar Orientale basin: origin as a single pyroclastic eruption. Presented at the 28th Lunar and Planetary Science Conference, Houston, Texas, 17-21 March 1997. Abstract no. 1244.

Lipsky, Y. N., 1965a. Zond-3 photographs of the moon's far side, *Sky and Telescope*, 338-341, Dec. 1965.

Lipsky, Y. N. (ed.), 1965b. *Atlas obratnoi storony Luny: Chast'2* (Atlas of the Far-side of the Moon: Part 2), Moskow: Nauka, 1965.



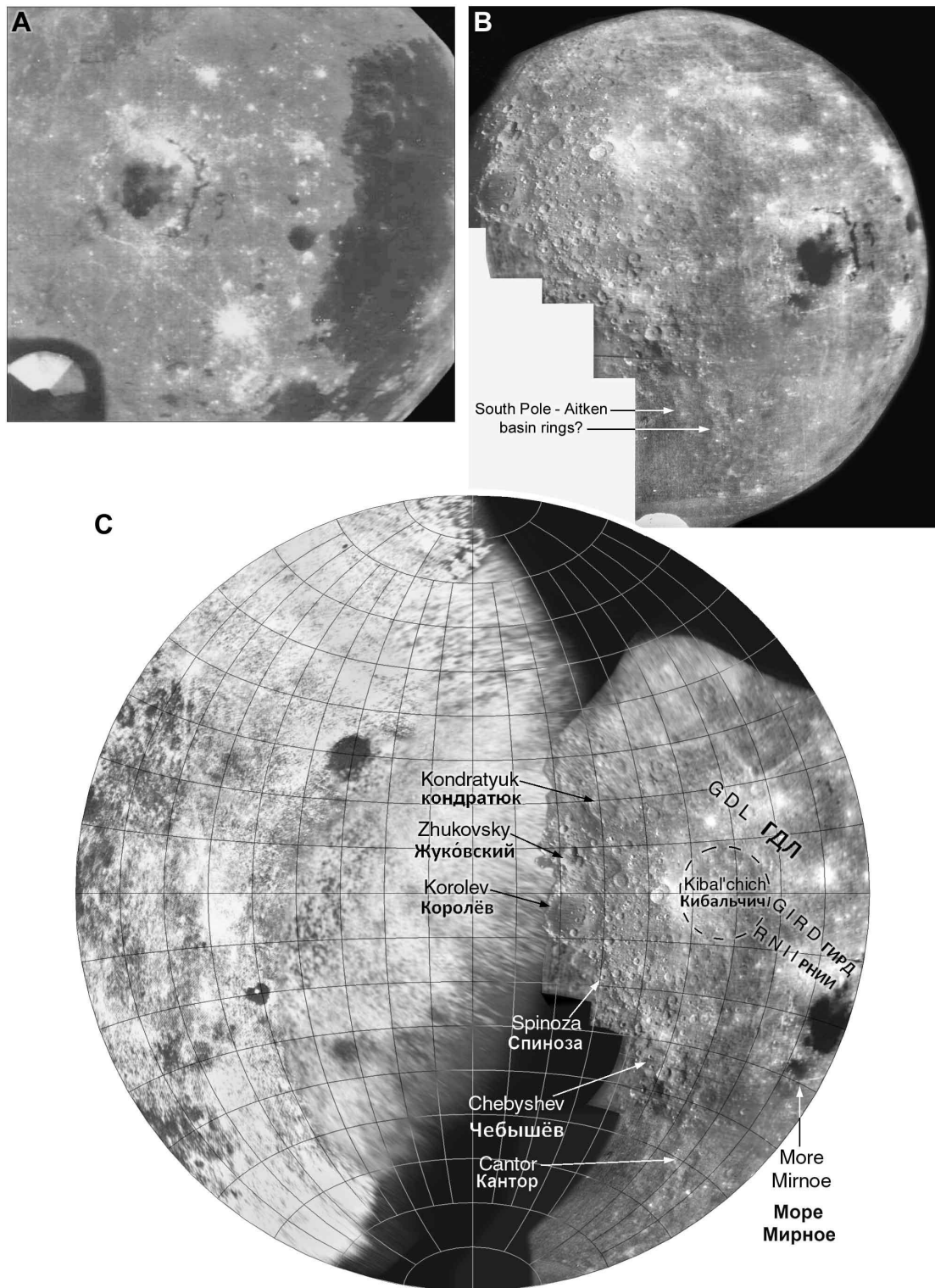


Figure 37: Zond 3 images of the Moon, and composite of Luna 3 and Zond 3 images. A: Image showing Oceanus Procellarum at right. B: Mosaic of Zond 3 images of the farside. C: Farside composite map showing the combined Luna 3 and Zond 3 coverage with the contemporary feature names in the Zond 3 image area. This map follows Figure 11C and is continued in Figure 52A.

04 October 1965: Luna 7

Luna 7 was another Soviet lunar soft landing attempt. The 1504 kg spacecraft, identical to its precursors, was launched from Baikonur at 7:55 UT, targeted for the western part of Oceanus Procellarum (Figure 38B) somewhere near 10° N, 58° W. A trajectory correction was made on 5 October. A premature firing and cutoff of the retrorockets (NSSDCA says a loss of attitude control prevented the braking burn) resulted in the spacecraft striking the lunar surface at 22:08 UT on 7 October at about 9.8° N, 47.8° W, in the general vicinity of its target area. This location is given by NSSDCA, but other sources vary. The landing site targets for early Luna missions (Figure 38B) were all in western Oceanus Procellarum, a little further west than the early Ranger targets (Figures 15B, 16C). This is just a general target region, and each mission had a more specific target within this region, in areas largely free of crater rays as described previously for Luna 4 and Ranger 7 site selection.

U. S. scientists, alerted by the reported Luna 5 impact observation (Figure 31), observed the expected impact area closely. A small marking at 9° N, 51° W (Figures 38C, 38D) was seen in photographs made at the Pic du Midi Observatory, but the observations were not considered conclusive (Musgrove, 1965). Johnson (1979) gives an impact location of 9° N, 49° W. Figure 38C shows the Luna 7 impact area, and Figure 38D illustrates it in greater detail. Given the many uncertainties, it is not feasible to locate the impact crater in high resolution images.

Rumours that Luna 7 transmitted for 3 seconds after landing were probably based on a mistranslation of statements about the cessation of signals. The early braking would result in impact slightly later than the predicted time. The impact location is probably uncertain by up to 20 km, so 10° N, 48° W would be a more realistic statement of the impact position. The impact site lies south or southeast of the crater Marius in Oceanus Procellarum (Figure 38C).

Johnson, N. L., 1979. *Handbook of Soviet lunar and planetary exploration*. Science and Technology Series, v. 47. San Diego: Univelt, Inc.

Musgrove, R. G., 1965. *Microdensitometer analysis of Luna 7 impact*. MSC Internal Note no. 66-ET-3. Houston, Texas: Manned Spacecraft Center, 15 December 1965.



03 December 1965: Luna 8

Luna 8 was the 11th lunar soft landing attempt by the Soviet Union, and the last in the long run of failed landings. With growing experience and successive improvements to the flight systems following each failure, the stage was now set for the first successful landing. Luna 8 was the last lunar flight observed by Sergei Korolev before his unexpected death on 14 January 1966.

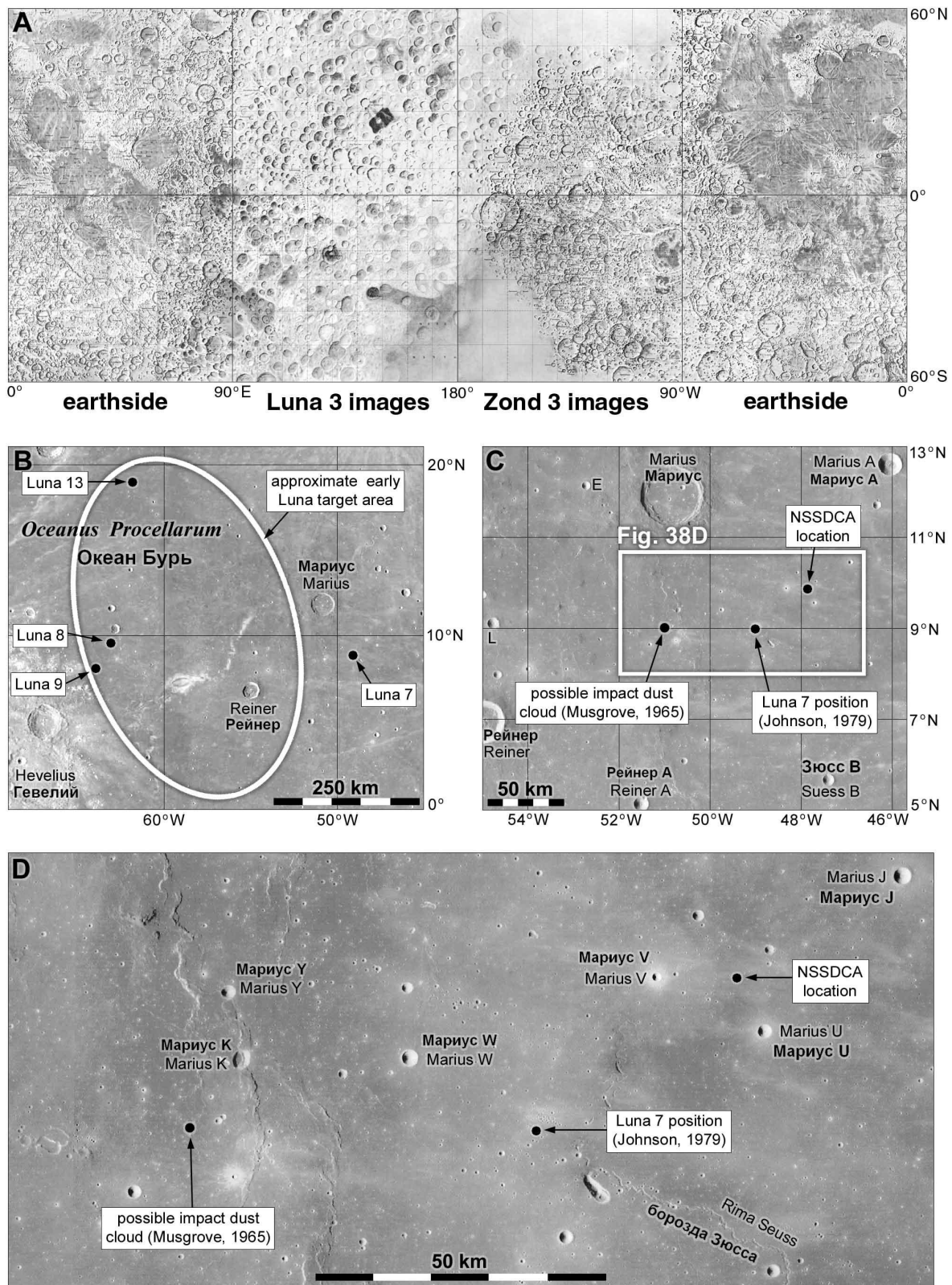


Figure 38: First complete map of the Moon, and the Luna 7 impact site. A: The equatorial section of the first complete map of the Moon incorporating Zond 3 data, courtesy of the Sternberg State Astronomical Institute. B: The early Luna target area. C, D: Luna 7 impact region south of Marius crater with three suggested locations.

The 1552 kg spacecraft was launched from Baikonur at 10:48 UT on 3 December and followed its planned trajectory closely with everything functioning normally. A trajectory correction was made on 4 December. Shortly before the retrorocket was due to ignite two protective air bags around the lander were set to inflate, but one of the two air bags was punctured, probably by an adjacent mounting bracket. A jet of escaping air pushed the spacecraft into an unexpected spin, and though it was briefly able to stabilize itself and begin a 9 second retrorocket burn, it soon began to tumble. The retrorocket burn was insufficient for a safe landing and the spacecraft crashed close to its target at 21:52 UT on 6 December. NSSDCA originally gave the position as 9.6° N, 62.0° W in western Oceanus Procellarum but Johnson (1979) stated 9° 08' N, 63° 18' W (9.13° N, 63.30° W), as shown in Figure 39C, and NSSDCA later dropped its site and adopted Johnson's position. The impact site is south of the crater Galilaei and west of the Marius Hills, a cluster of volcanic mounds which were considered a possible Apollo target in later years.

Figure 39A shows the Luna 8 impact region. The darker mare area around Galilaei crater was the target for this mission and for Luna 9. An approximate target ellipse is shown in Figure 39A, but the dimensions of the target area are not certain and it should not be considered definitive. Ray-free areas were assumed to be smoother and safer to land in. Figure 39B shows more detail of the Luna 8 impact area and identifies the two locations given by NSSDCA and by Johnson (1979). Figure 39C shows the impact area in more detail in an LROC wide angle camera mosaic. It is not possible to identify the impact site on high resolution images because the location is so uncertain.

Johnson, N. L., 1979. *Handbook of Soviet lunar and planetary exploration*. Science and Technology Series, v. 47. San Diego: Univelt, Inc.



31 January 1966: Luna 9

Luna 9 was the first spacecraft to achieve a lunar soft landing and to transmit images and other data from the surface. The long series of failures now gave way to a spectacular success and a major propaganda coup for the Soviet Union.

The whole Luna 9 spacecraft including navigation equipment and retrorocket weighed 1580 kg, but the 60 cm diameter landing module or 'automatic lunar station' (ALS), Luna 9 itself, weighed only 99 Kg. It was a sealed, pressurized egg-shaped vessel containing radio equipment, a timing control device, heat control systems, scientific apparatus, batteries and a television system. The main spacecraft descended until a long rod under the vehicle touched the surface, at which point the descent thrust was terminated and the lander was ejected. It fell to the surface protected in an airbag system which was then discarded, leaving the lander to begin operations.

The Luna 9 spacecraft was launched from Baikonur at 11:45 UT on 31 January 1966 and propelled toward the Moon by a fourth stage rocket that later separated itself from the payload. The upper stage passed the Moon and continued into heliocentric orbit. There was one trajectory correction 233 000 km from Earth at 19:29 UT on 1 February. Landing occurred on 3 February at 18:45 UT.

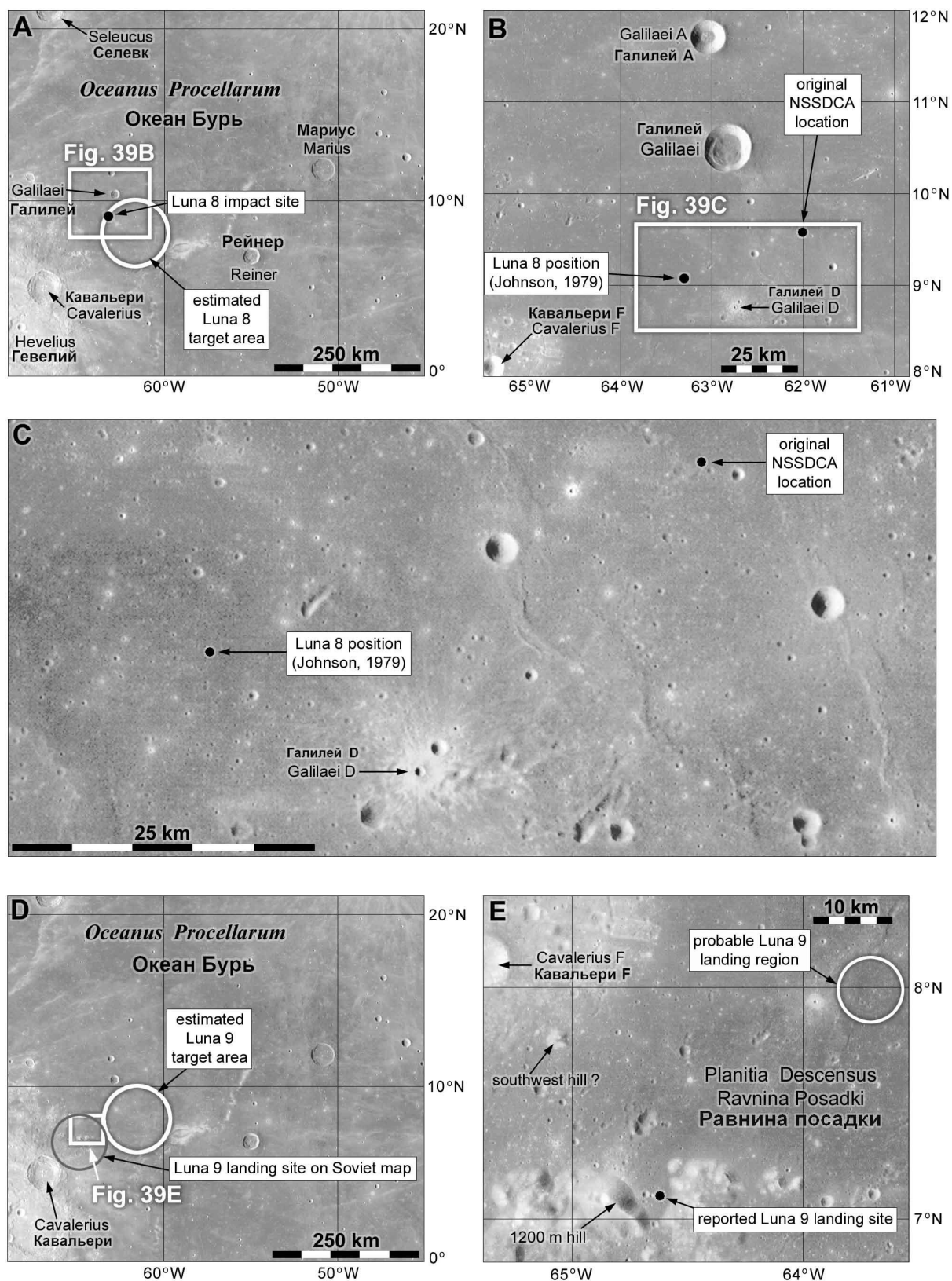
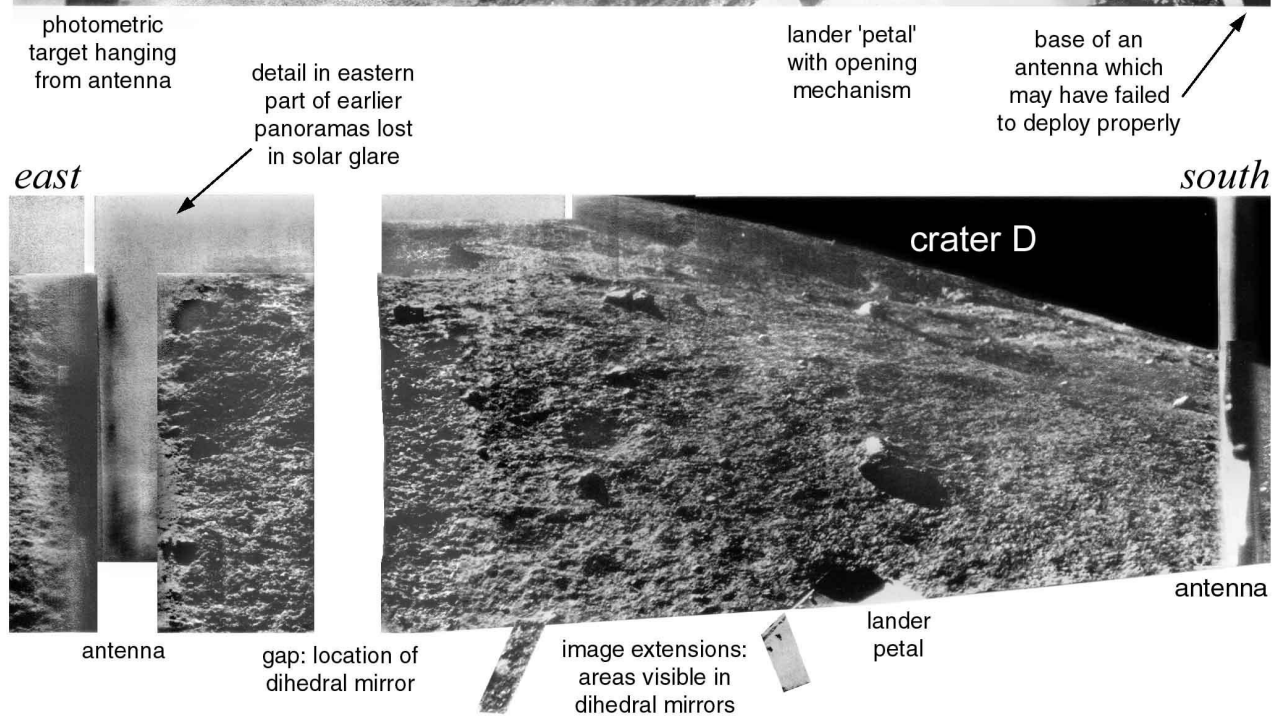
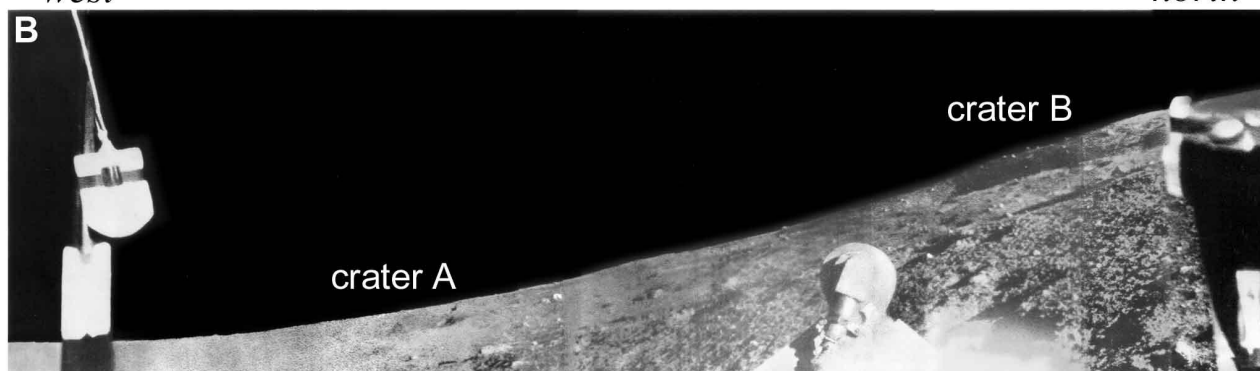
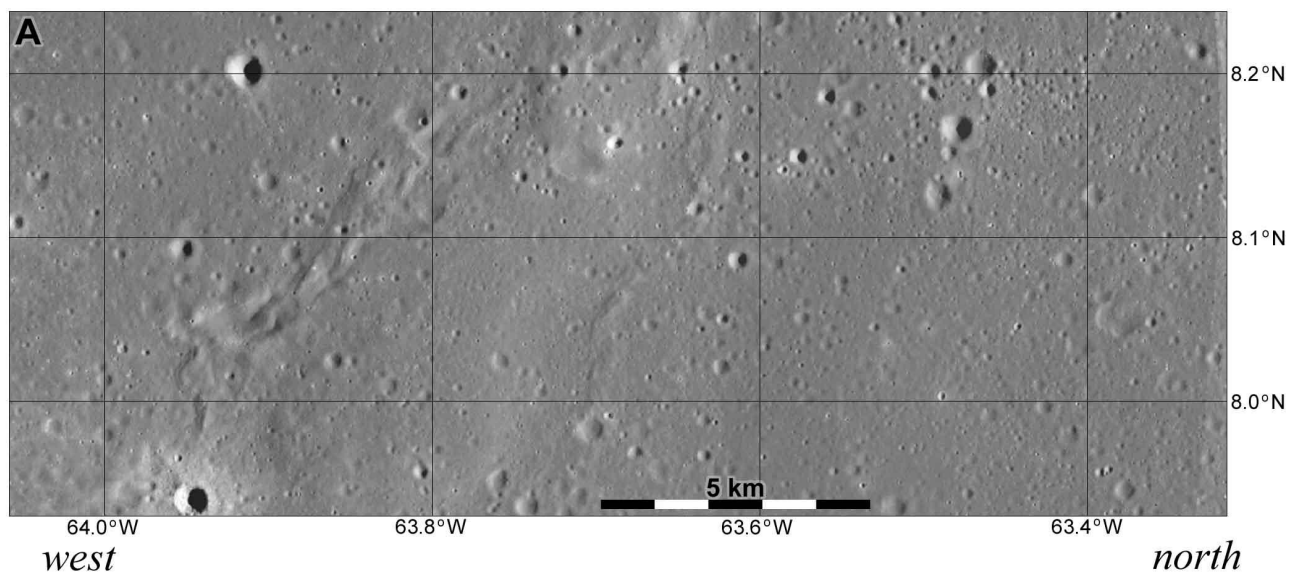
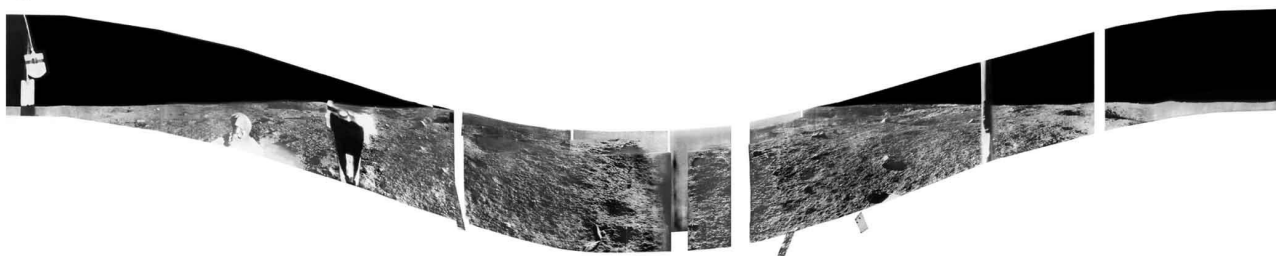


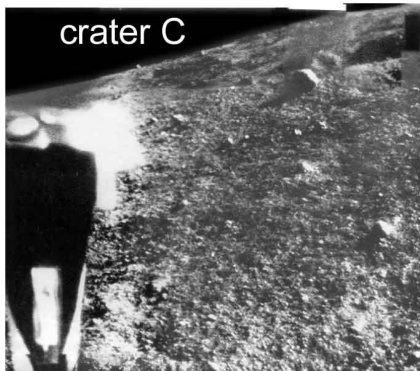
Figure 39. The Luna 8 and Luna 9 sites. A: Luna 8 target and impact regions. B, C: Luna 8 impact area on LROC images. D: Luna 9 target and landing areas. E: Luna 9 landing region.



C



north



east

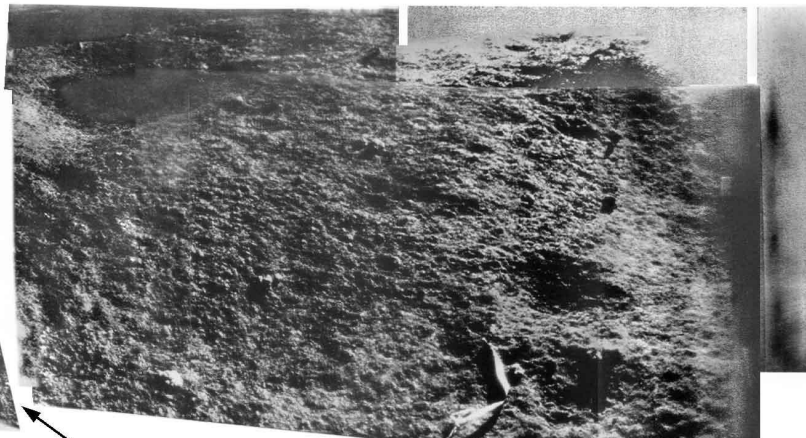
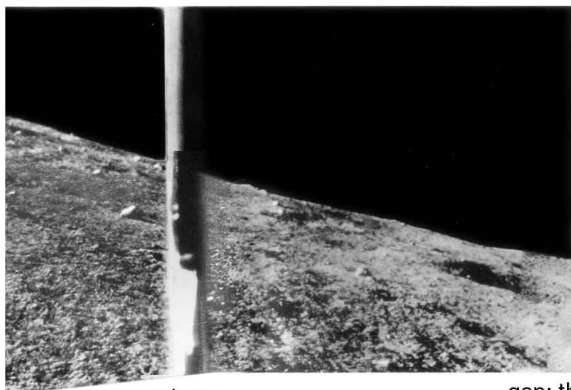


image extension:
area visible in mirror

gap: location of
dihedral mirror

strap or tape
from petal just
below image

south



antenna

gap: third mirror

west

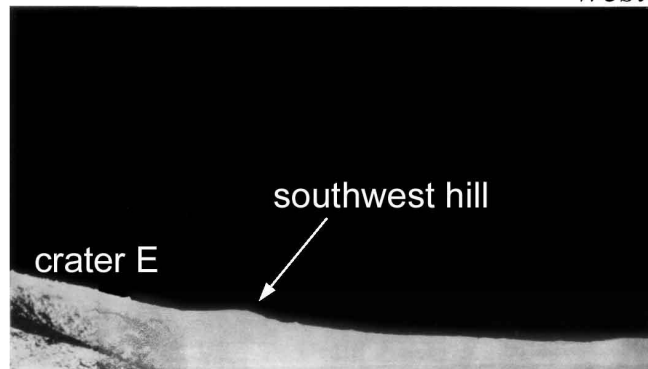


Figure 40 (both pages). Luna 9 landing area and panorama. A: The landing site is probably in the central part of this image (LRO wide angle mosaic). B: composite of all Luna 9 images by P. Stooke (4 panels). C: geometrically rectified Luna 9 panorama showing the flat horizon.

The main spacecraft crash-landed at about 6 m/sec after braking almost to a standstill just above the lunar surface, but the ALS separated from it, bouncing in a padded protective shell which was then discarded. Neither the main spacecraft hardware nor the padded shell can be seen in the surface photographs, suggesting the capsule rolled some distance before stopping or that they lie in areas outside the image coverage.

The egg-shaped battery-powered lander unfolded four petals on its upper half, exposing its instruments and assuming the correct orientation in the process. Four spring-loaded antennae and three narrow dihedral mirrors erected themselves and the scanning television camera began a photographic survey of the surrounding landscape. Seven radio sessions totalling 8 hours and 5 minutes were held, including the transmission of panoramic images. The pictures included views of nearby rocks and the horizon, and finally laid to rest fears that dust would engulf a lander. To the chagrin of Soviet scientists, some images were received by British scientists at the Jodrell Bank radio telescope and released to the world prematurely, in a distorted format (this event is sometimes associated incorrectly with Luna 3). Activities ended at about 10:55 UT on February 6 when the batteries were exhausted.

The landing site (Figure 39D) was near 8° N, 64° W in western Oceanus Procellarum (Figure 69). The coordinates often given, 7.08° N, 64.37° W (NSSDCA) or 7.13° N, 64.37° W (Roncoli (2005); note that 8' of arc is 0.13° so one of these latitudes may be a mistaken reading of the other), are misleadingly precise. The Luna 9 target was a region of dark (ray-free) mare, probably that centered near 8° N, 62° W, the same as the Luna 8 target. Wilhelms (1993) gives the target position as 7° N, 64° W but this is probably too close to the highlands.

Figure 39E depicts the Luna 9 landing region in more detail, including the location usually identified as the landing site on the basis of tracking and a more likely landing location further north. The landing region was named Planitia Descensus (Plain of Landing) by the International Astronomical Union, and was labelled as *Zaliv Priluneniya* on contemporary Russian maps and *Ravnina Posadki* on current maps. The landing occurred near the highland/mare boundary northeast of the 60 km crater Cavalerius (Figure 39D). The coordinates derived from tracking place the lander between or just north of several prominent mountains, up to 1200 m high, which form part of the rim of an ancient crater. However, the surface panoramas include more than half of the horizon from south through west to north, and no mountains can be seen. A Soviet map provided to the author by the Embassy of the USSR in London, UK in about 1969 showed a circle representing the landing location which is c. 3° or 100 km in diameter (Figure 39D). This encompasses the region to the north of the nominal site which is illustrated in Figure 39E.

The horizon in panoramas (Figure 40) is irregular in some places, suggesting relief resembling a mare ridge or small crater rims. Other parts of the horizon are nearly flat. It seems most likely that Luna 9 landed in a mare area far enough from the highlands that the mountains are not visible over the southern horizon. Local relief on that southwestern horizon might conceal mountains which would project above the ideal spherical horizon, so an exact distance cannot be specified. One small hill is visible to the southwest, but it is not clear whether this is minor local relief perhaps 1 km away, or a larger mountain at a considerable distance. It is tempting but unverifiable to equate this feature with the 'southwest hill' or the 1200 m hill in Figure 40A.

These considerations suggest a site closer to 8° N, 64° W (circled in Figure 39E), at least 30 km (1°) from the Soviet position. Moving slightly further east allows a low mare ridge to conceal the prominent hills. The undulating terrain covered with Cavalerius ejecta, south of the mountains near 6.6° N, 65.0° W, appears to be too hilly to allow for a flat horizon. These uncertainties make a search for the Luna 9 lander in LROC images very difficult. All things considered, a location near 8.0° N, 63.67° W seems most likely.

The Luna 9 camera rotated through 360°, pointing downwards to the east and upwards to the west because of the tilt of the lander. Three nearly complete panoramas were transmitted by Luna 9 and a fourth was commencing when the lander batteries failed. Glare from the rising sun interfered with visibility in the east, but this was reduced by the higher sun angle in the third panorama. The spacecraft moved slightly between each of the panoramas. The composite view shown here (Figure 40B) combines parts of all available panoramas to fill several data gaps and areas lost in glare, and to maximize coverage as the camera shifted. Three dihedral (two-sided) mirrors reflected six narrow strips of the terrain to permit triangulation for cartographic purposes. Three areas seen only in the mirrors have been added to the bottom of the composite panorama. The others have not been located.

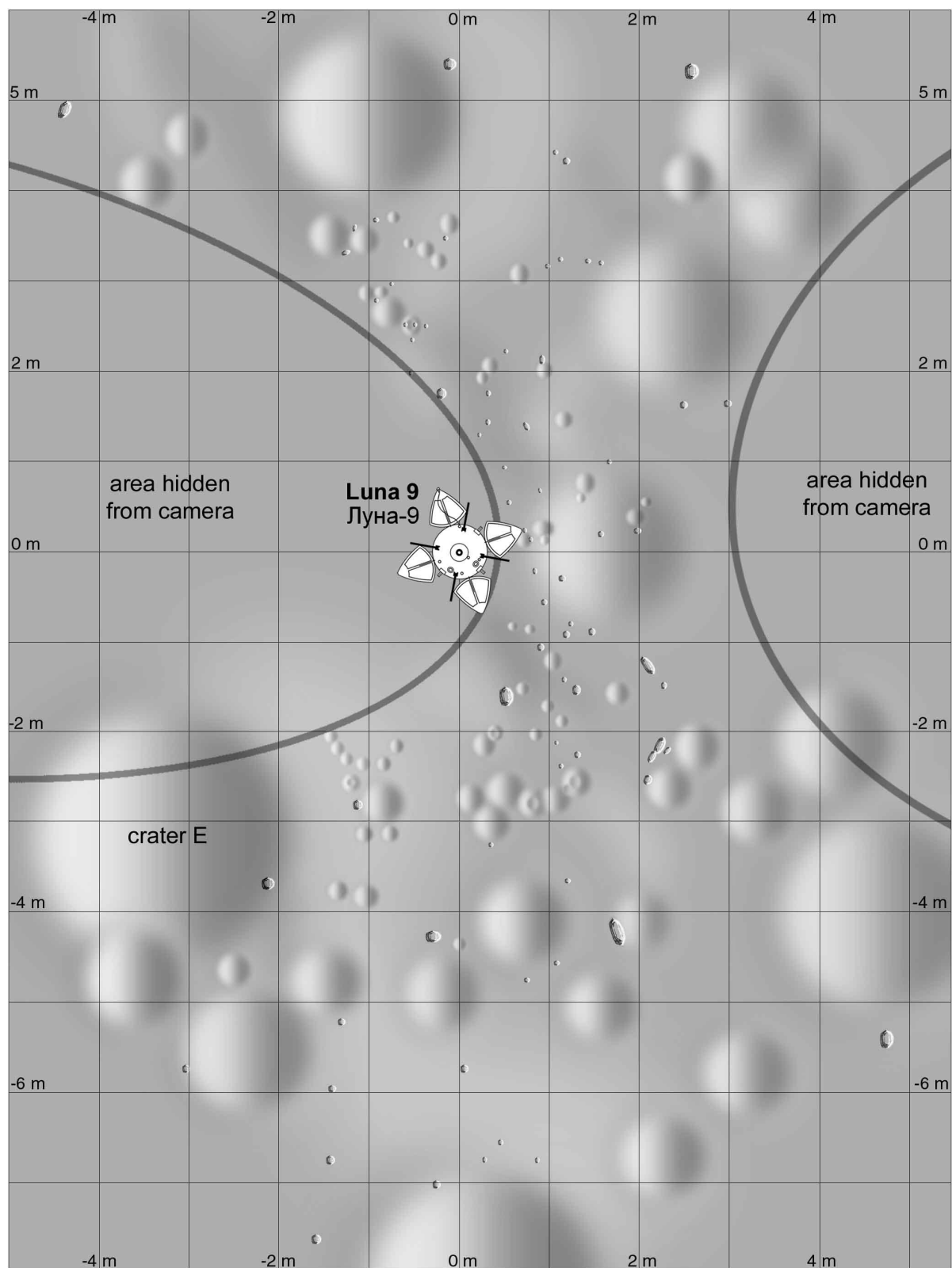


Figure 41. Luna 9 landing site. This is a shaded relief rendition of a map originally at 1:40 scale in Academy of Sciences of the USSR (1966). See also Shoemaker *et al.* (1966). Approximate contours on the original have been omitted but are reflected in the shading. A drawing of the spacecraft, to scale, has been added.

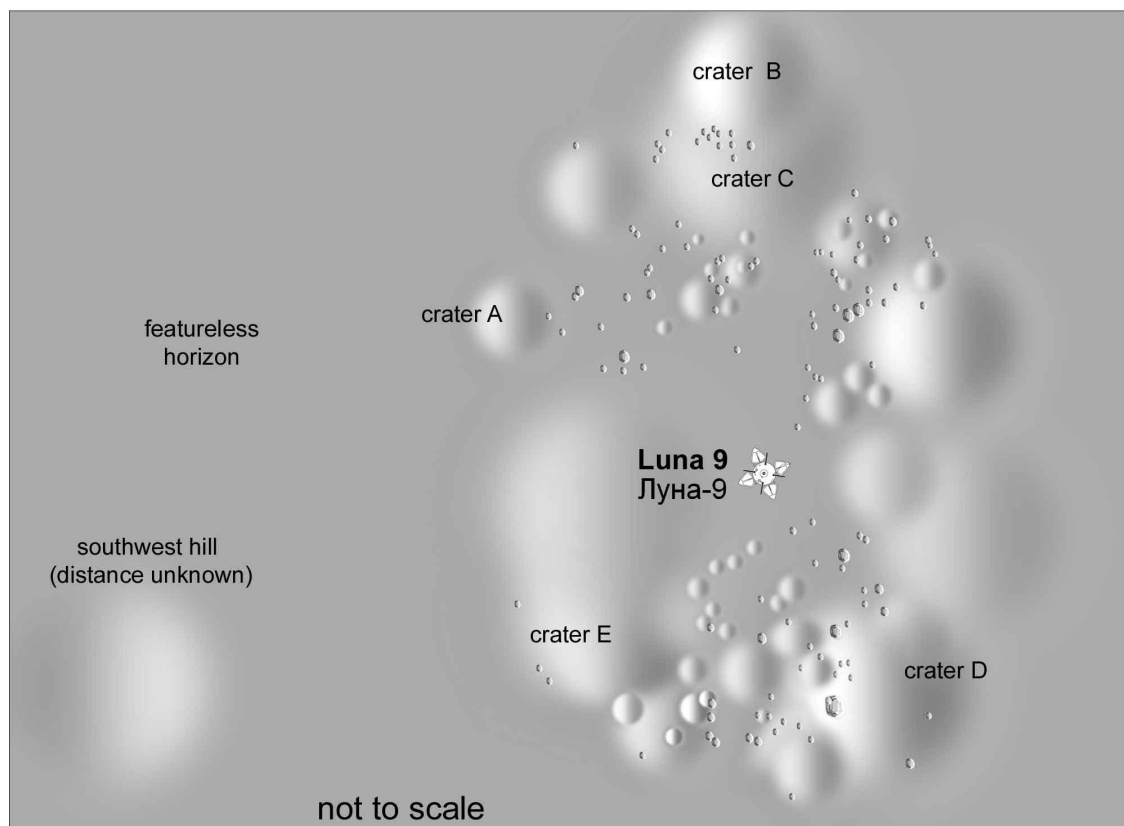
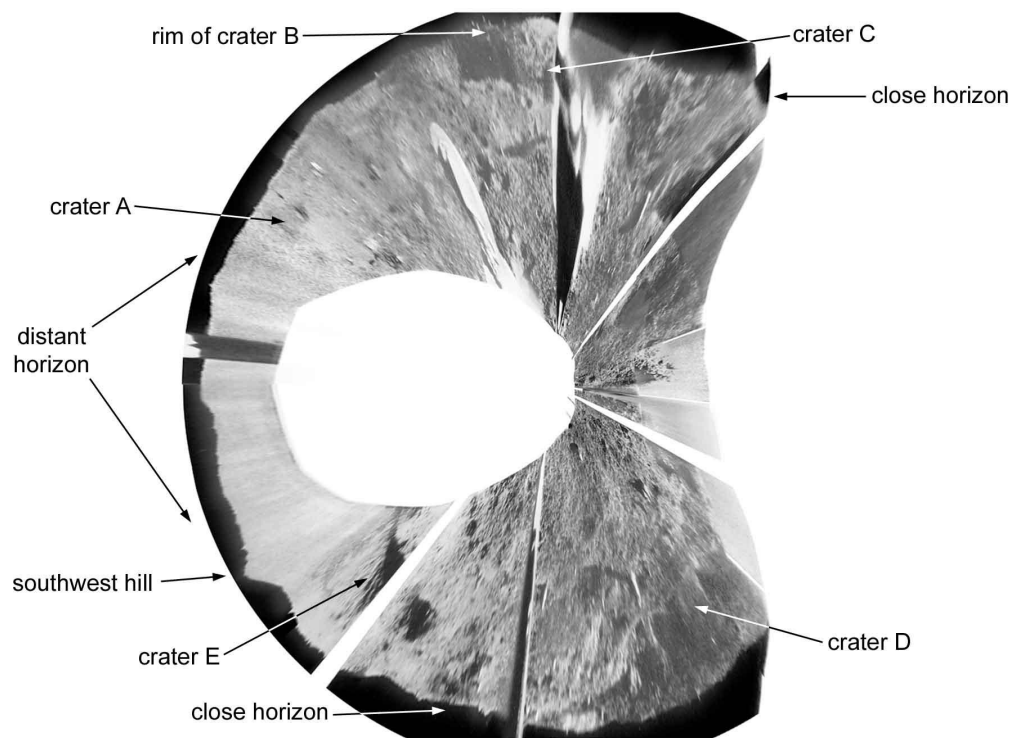


Figure 42. Luna 9 landing site. A: reprojection of the panorama in Figure 40B to a more map-like geometry, with exaggerated horizon relief. B: relief drawing derived from Figure 42A. No true scale can be shown, but this map probably extends about 100 m from north to south with a more distant western horizon. Map by P. Stooke.

Before the first panorama was made, a small test image was transmitted at a sun angle of only 3.5°. The last partial panorama was degraded by low power levels. These images were never released. Soviet statements described the horizon as being 1.5 km from the lander, but this was merely a generalization based on the mean curvature of the lunar surface. Much of the horizon is no more distant than about 100-200 m, as shown by the clearly resolved rocks visible against the black sky. Only in the west is more distant topography visible. An approximately rectified version of the composite panorama showing a flat horizon is shown at reduced scale in Figure 40C. The foreground of the panorama, visible in the east, extends only a few metres from the lander and is partly hidden by solar glare in the earlier images. North and south of the landed spacecraft, rocks and craters extend out to an undulating horizon a few tens of metres away. In the west, where detail is washed out by the sun angle, the horizon extends to an unknown distance, perhaps several km. The NSSDCA description of the mission says the spacecraft landed near the rim of a 25 m diameter crater. This is an interpretation of the area to the west where the crater's near rim is not visible and the far rim forms the terrain just below the horizon. It is possibly seen in Figure 42 (top).

The Luna 9 images were described in Academy of Sciences of the USSR (1966) and commented on by Shoemaker *et al.* (1966) and the Lockheed Electronics Company (1968). The latter analysis suggested that Luna 9 landed inside a crater, perhaps the source of the NSSDCA comment. The USSR book included two maps of the landing site which are combined and rendered in shaded relief form in Figure 41. Features close to the lander are reliably located, but in the absence of elevation data (other than a very small amount derived from analysis of strips reflected in the dihedral mirrors) the more distant features can only be approximately located. The nature of the horizon is also illustrated with a different reprojection of the panorama (with exaggerated horizon relief) in Figure 42A, and from this a different interpretation of distant features is presented in Figure 42B. Craters identified by letters are identified in the panorama (Figure 40B) and in Figure 42.

Academy of Sciences of the USSR, 1966. *First panoramas of the lunar surface*. Moscow: Akademiya Nauk.

Lockheed Electronics Company, 1968. *Analysis of Luna 9 photography*. NASA Contractor Report CR-980, February 1968.

Roncoli, R., 2005. Lunar Constants and Models Document. Jet Propulsion Laboratory Technical Document D-32296, 23 September 2005. https://ssd.jpl.nasa.gov/doc/lunar_cmd_2005_jpl_d32296.pdf.

Shoemaker, E.M., Batson, R.M. and Larson, K.B., 1966. An appreciation of the Luna 9 pictures. *Astronautics and Aeronautics*, v. 4, no. 5, pp. 40-50.

Wilhelms D. E., 1993. *To a Rocky Moon: a geologist's history of lunar exploration*. Tucson: University of Arizona Press.



01 March 1966: Luna (Cosmos 111)

This mission was intended to orbit the Moon, similar to the later Luna 10 mission. The spacecraft was launched from Baikonur at 11:02 UT. The upper stage engine burn, intended to place the spacecraft on its lunar trajectory, was cancelled after the vehicle lost attitude control while in its parking orbit. It re-entered the atmosphere after two days. The failed mission was designated Cosmos 111 to conceal its original purpose.



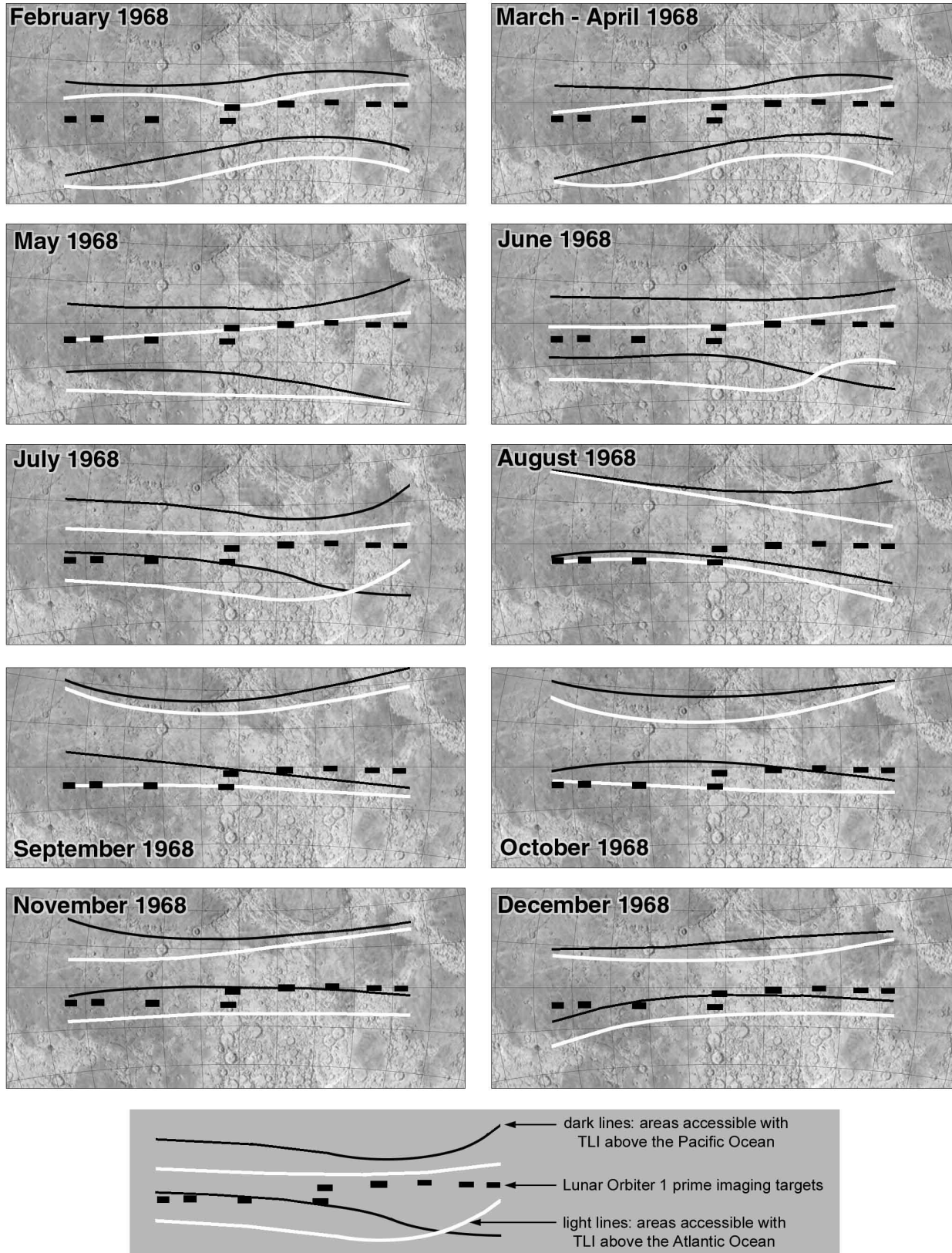


Figure 43: Apollo monthly accessibility diagrams for 1968.

16 March 1966: Apollo Site Selection Board

Before the fatal Apollo 1 fire of 27 January 1967, it seemed possible that the first landing might happen as early as 1968. At this first meeting of the Apollo Site Selection Board the site selection process began by considering which areas on the Moon would be accessible during that year. The accessible area varied from month to month as the illumination conditions and position of the Moon in its inclined orbit changed. For any one month it also depended on the location on Earth (Atlantic or Pacific Oceans) above which the trans-lunar injection (TLI, the rocket burn to send the vehicle to the Moon) would occur. This determined the inclination of the subsequent lunar orbit.

Figure 34B shows the narrow area accessible most frequently in 1968 and the broader region accessible occasionally during the year. That accessibility map was compiled from calculations for individual months (Figure 43), based on diagrams presented at the following ASSB meeting on 1 June 1966.

Figure 43 shows the lunar accessible areas for Atlantic TLI (white outlines) and Pacific TLI (black outlines). An Atlantic TLI makes southern areas more accessible, while a Pacific TLI favors the north. The small black rectangles in Figure 43 are the areas designated as Lunar Orbiter 1 prime sites, the imaging targets for that mission (Figure 50) which were considered potential Apollo landing sites in June 1966. Some sites in the west (Oceanus Procellarum) are only marginally accessible, if at all, from August to October 1968.



31 March 1966: Luna 10

The Soviet Union's Luna 10, the first spacecraft to enter lunar orbit, was launched from Baikonur at 10:48 UT. It entered a parking orbit and was then placed on a lunar trajectory by a burn of its upper stage. A trajectory correction was made on 1 April. The 540 kg (Johnson (1979) gives a mass of 245 kg, probably not including fuel) battery powered spacecraft was a cylinder 80 cm in diameter and 150 cm long, tapering eccentrically at one end, with four antennae at one end and instrument ports distributed over its body. It travelled to the Moon on a module like that which carried the earlier landers but separated from it in orbit. Both components are probably still in orbit (Powell 2003).

Luna 10 entered a 350 by 1015 km lunar orbit with a period of 178 minutes, inclined 72° to the lunar equator, at 18:44 UT on 3 April. Scientific instruments included a gamma-ray spectrometer, a magnetometer on a 1.5 m boom, a meteorite detector, solar plasma detectors, a lunar infrared emission monitor and radiation detectors. Luna 10 may have carried a camera which failed to work. The lunar gravity field was studied by spacecraft tracking. The spacecraft transmitted the revolutionary anthem '*Internationale*' during the Twenty-third Congress of the Communist Party of the Soviet Union.

Luna 10 functioned for 460 lunar orbits with 219 transmission sessions before its batteries failed on 30 May 1966. Its orbit height at that time was 378 by 985 km. Valuable information was obtained, including the first compositional data on the lunar surface which suggested that the maria consisted of basalt and the highlands of ultrabasic rocks, as substantially confirmed by later missions (Vinogradov *et al.*, 1966). Earth's extended magnetosphere was not detected as the Moon passed through it, nor was any sign of a lunar dipole field detected (Dolginov *et al.*, 1966). Trapped radiation belts similar to those of Earth were shown not to exist around the Moon, and tracking of the orbit revealed unexpected irregularities in the Moon's gravitational field (Akim, 1966).

Akim, E. L., 1966. Determination of the gravitational field of the Moon by the motion of the AMS Luna-10. NASA translation ST-CM-LPS-10532.

Dolginov, Sh. Sh., Yeroshenko, E. G., Zhuzgov, L. N. and Pushkov, N. V., 1966. Measurements of the magnetic field in the vicinity of the Moon on the AMS Luna-10. NASA translation ST-PF-LPS-10530.

Johnson, N. L., 1979. *Handbook of Soviet lunar and planetary exploration*. Science and Technology Series, v. 47. San Diego: Univelt, Inc.

Powell, D., 2003. The Moon's own moons. *Astronomy Now*, v. 17, no. 9, September 2003, pp. 38-39.

Vinogradov, A. P., Surkov, Yu. A., Chernov, G. M. *et al.*, 1966. Measurements of Gamma Radiation of the lunar surface on the space station Luna-10. NASA translation ST-LPS-ACH-10517.



30 April 1966: Luna 1966A

Luna 1966A is thought to have been intended as a Soviet lunar orbiter similar to Luna 10. It was launched from Baikonur but the SL-6/A-2-e launch vehicle failed and did not place the payload in orbit.



30 May 1966: Surveyor 1

NASA's Surveyor spacecraft were designed to achieve controlled lunar landings in support of Apollo, helping to demonstrate the safety of candidate landing sites. Surveyor 1 was launched at 14:41 UT from Cape Canaveral on an Atlas-Centaur booster. The spacecraft approached the Moon at 9700 km/h, began braking 3200 kilometers above the surface, slowed to 5.6 kilometers per hour at 4 m high and fell from there to the surface, landing at 13 km/h. It landed near the crater Flamsteed in Oceanus Procellarum at 06:18 UT on 2 June at 2.533° S, 43.377° W (JPL 1966; JPL 1969). Updated coordinates based on LRO mapping are 2.474° S, 43.339° W (Wagner *et al.*, 2027), and the discrepancy is discussed below.

The spacecraft performed flawlessly for a lunar day, then was shut down for the lunar night following some battery-powered operations after sunset, and was revived for a second day on 7 July, ending routine operations on 14 July. It transmitted 11,240 images and data on the strength, temperature and radar reflectivity of the Moon. Radio contact with the spacecraft was maintained until January 1967, surviving eight day-night cycles, though no further science data could be obtained.

The spacecraft mass was 1,000 kg at launch and about 275 kg at landing. The lander consisted of a tetrahedral tubular aluminium frame with three legs having circular footpads, topped by a mast holding a solar panel and high gain antenna. Surveyor stood 3 m high and 3.5 m wide at the base. A spherical retrorocket assembly inside the spacecraft frame braked it during the descent. It was ejected at about 14 km altitude and fell near the landing site. The descent continued using three small variable-thrust vernier engines. No Surveyor retrorocket was imaged by its lander, and the Apollo 12 astronauts who visited Surveyor 3 did not see its retrorocket, but evidence for them was later found in Lunar Reconnaissance Orbiter images (Stooke, 2016).

Surveyor 1 carried a television camera intended to perform a detailed survey of the landing site, capable of operating in wide-angle and narrow-angle modes. It also carried a descent imaging camera which would have transmitted images between 1500 km and 140 km altitude during the descent to the landing site, sufficient to locate the site fairly accurately though not providing extremely high resolution images. Concerns about the complexity of operations and the interruption of flow of vital engineering data in what was viewed primarily as an engineering test flight led to the descent camera not being turned on during flight. An attempt was made to use it after landing to test the electronics, but it failed. Other than these cameras the spacecraft carried only engineering sensors.

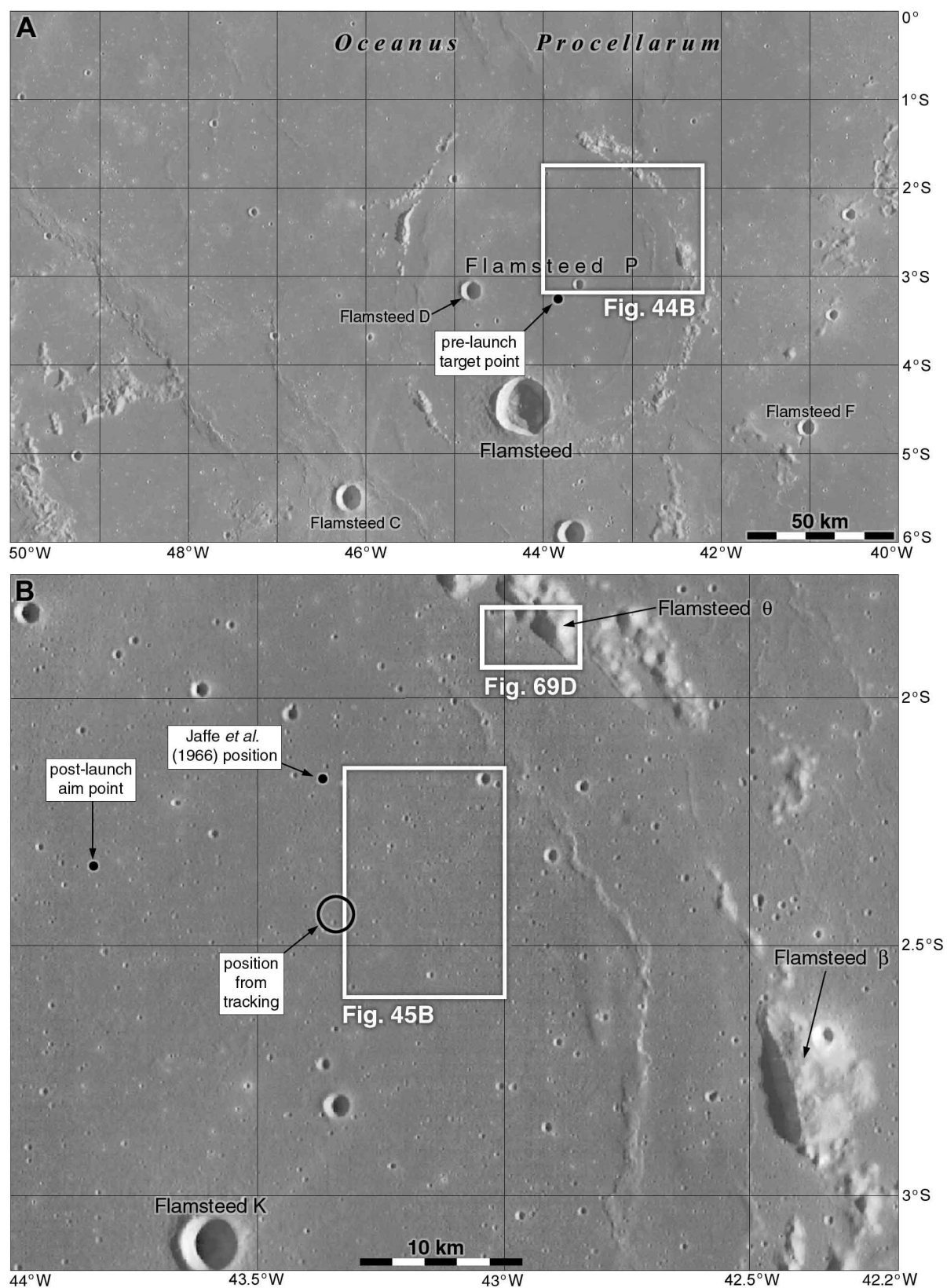


Figure 44. The Surveyor 1 landing region. The area around the Surveyor 1 landing site. The base is an LROC wide angle mosaic. The coordinates are adjusted slightly to match those in use at the time.

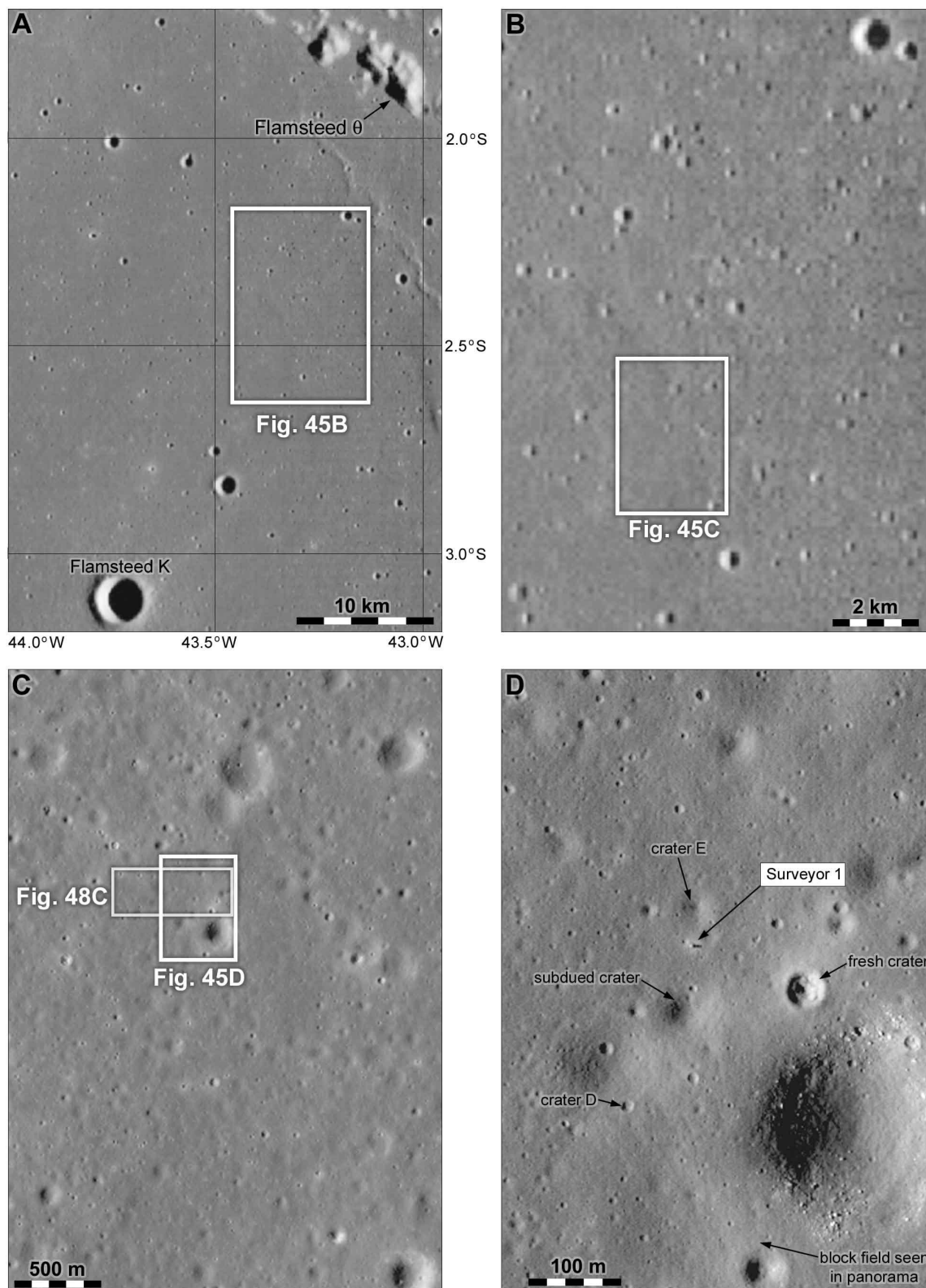


Figure 45: The Surveyor 1 landing site. The four images locate the lander in LROC images. A and B are LROC wide angle mosaics. C and D are details from LROC narrow angle image M181451964L. Features visible in Figure 46 are indicated in Figure 45D.

Surveyor 1 carried a television camera intended to perform a detailed survey of the landing site, capable of operating in wide-angle and narrow-angle modes. It also carried a descent imaging camera which would have transmitted images between 1500 km and 140 km altitude during the descent to the landing site, sufficient to locate the site fairly accurately though not providing extremely high resolution images. Concerns about the complexity of operations and the interruption of flow of vital engineering data in what was viewed primarily as an engineering test flight led to the descent camera not being turned on during flight. An attempt was made to use it after landing to test the electronics, but it failed. Other than these cameras the spacecraft carried only engineering sensors.

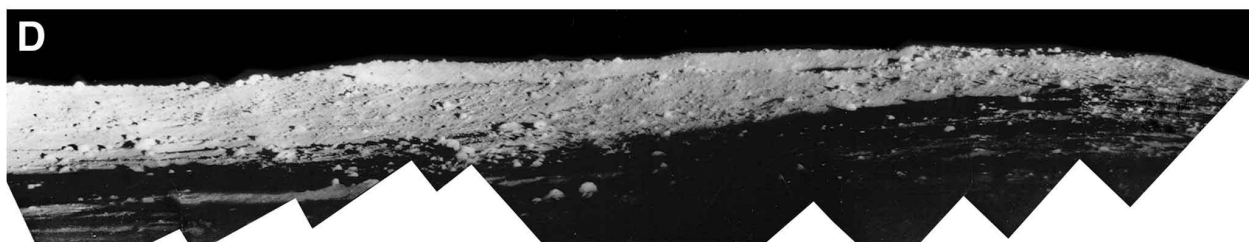
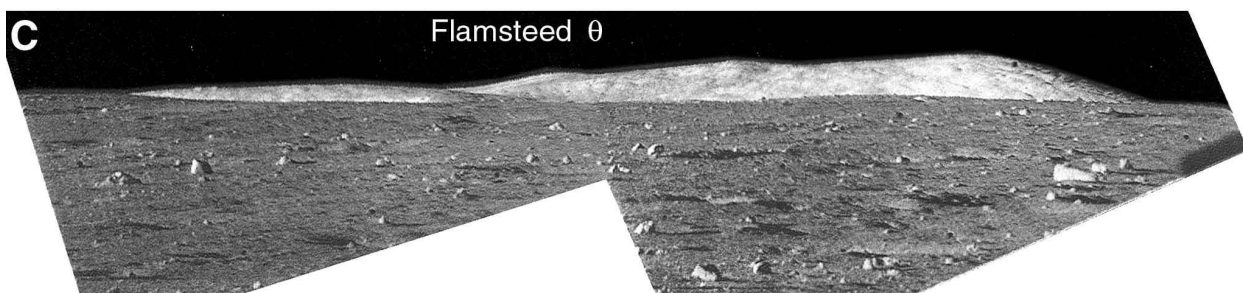
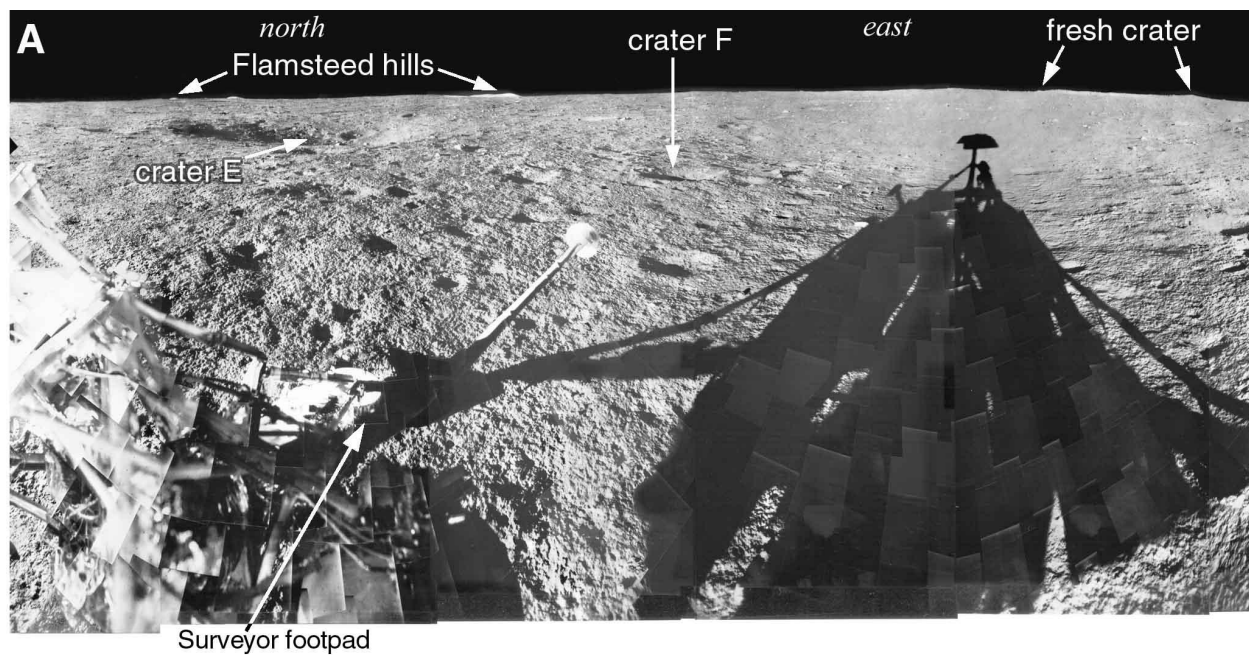
The Surveyor 1 target before launch was a 50 km radius circle in Oceanus Procellarum centered at 3.25° S, 43.83° W, within the 100 km ring of hills and ridges called Flamsteed P (Figure 75). Jaffe (1967) suggested that this crater be named after Theodore von Kármán, one of the founders of JPL, who had died on 6 May 1963. The IAU instead gave his name to a more prominent crater on the lunar far side, the landing site of Chang'e 4 in 2019. After launch the accuracy of the trajectory allowed the target to shrink to a 29 by 39 km ellipse, whose centre (2.33° S, 43.83° W) was moved northwards from the original target by a mid-course correction to avoid the larger craters nearby such as Flamsteed K (Figure 44). If no correction or braking had occurred Surveyor 1's initial trajectory would have caused it to crash at 11.43° S, 54.15° W. Tracking suggested a landing 15 km east of the target at 2.49° S, 43.32° W.

Luna 9 did not provide data sufficient to locate its landing site precisely. Surveyor 1 images of the northern horizon revealed the hills Flamsteed θ (Theta) and Flamsteed ϕ (Phi) in the distance. These made a search for its location feasible, and so the Surveyor 1 landing site became the first to be identified on another world. Tracking suggested a landing at 2.49° S, 43.32° W (Figure 44). The Surveyor Scientific Evaluation and Analysis Team (Jaffe *et al.* 1966) tried to match observed hills on the horizon with features drawn on the ACIC chart of the area and found two possible matches. One coincided with the tracking position but did not fully account for the observed hills. The other, at 2.15° S, 43.35° W, gave a better match to the hills but was 10 km north of the tracking point and 5 km outside the uncertainty ellipse around that point.

Ewen Whitaker (University of Arizona) attempted to clarify this uncertainty by using the best original telescopic images of the area rather than the chart used by Jaffe *et al.* (1966). The images allowed a better match to the horizon features, giving a new location of 2.57° S, 43.34° W, very close to the tracking point (Whitaker, 1966). Later the spacecraft was unambiguously located in Lunar Orbiter 3 image LO3-183-H1 (Spradley *et al.*, 1967). Surveyor 1 appeared as a bright spot casting a 10 m-long shadow. With hindsight the spot was also visible in Lunar Orbiter 1 medium resolution images (e.g. LO1-192-M), but it could not be conclusively identified until the later image showed it more clearly. The length of the shadow was one of the deciding factors in its identification.

ACIC produced maps of the landing region for Apollo site studies (Figure 44B), and also to support the Surveyor 1 mission, based on high resolution Lunar Orbiter images. The Ranger charts used 2 or 3 letter designations for craters (Figures 23, 26, 27B, 29), but this practice was rarely used after Ranger, so most craters are unlabelled on large scale Surveyor or Lunar Orbiter maps. Despite the lander's location being known to within a few metres relative to nearby craters, its coordinates often varied significantly on maps and in published reports. For example, on ACIC lunar map ORB-I-9.2g(25), an Apollo site planning chart published in May 1967, Surveyor 1 is located at 2.45° S, 43.21° W. Only 8 months later (January 1968) on ACIC's map of the Surveyor 1 site at a scale of 1:2 000, the lander is shown at 2.533° S, 43.377° W. These are the same locations relative to surface features, and the difference is caused by uncertainties in positioning the source images on the map grid. This problem is present in all lunar literature of the period, and it makes comparisons of coordinates from different sources very difficult. At the time of writing (2025) LRO images registered to its laser altimeter provide the most accurate coordinates: 2.474° S, 43.339° W (Wagner *et al.*, 2027).

The Army Map Service also documented the Surveyor 1 landing site in a pictorial map. Figure 47 portrays the landing site based on a post-mission report (JPL, 1969), showing selected rocks and craters which are identified in the panoramic images (Figure 46). The camera faced east, so some areas to the west are mostly hidden behind the spacecraft body. A 2 m grid provides scale, with the spacecraft camera at the origin of the local coordinate system. A second version of the map shows the panorama projected to the geometry of the JPL map. This illustrates what could be done with Surveyor images when they become more widely available.



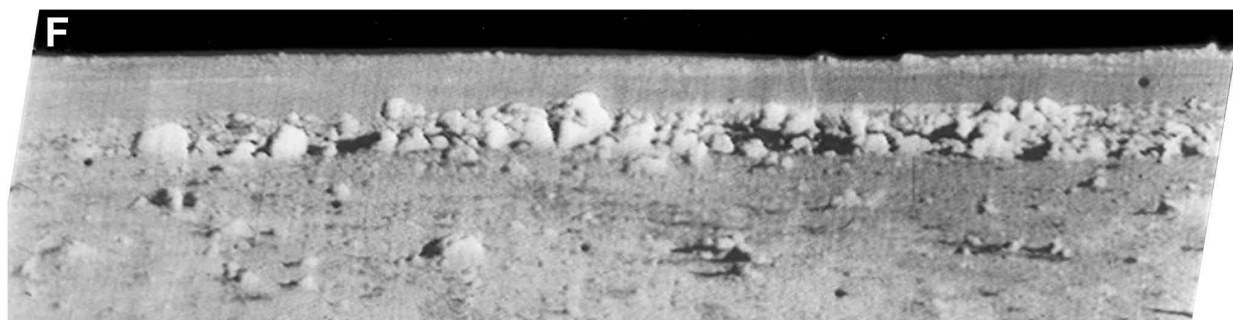
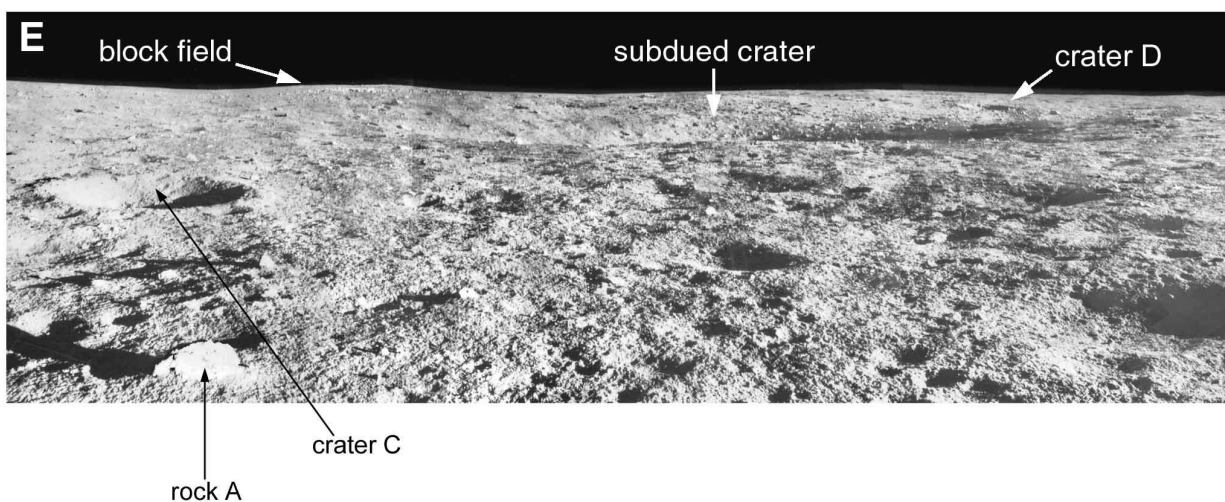
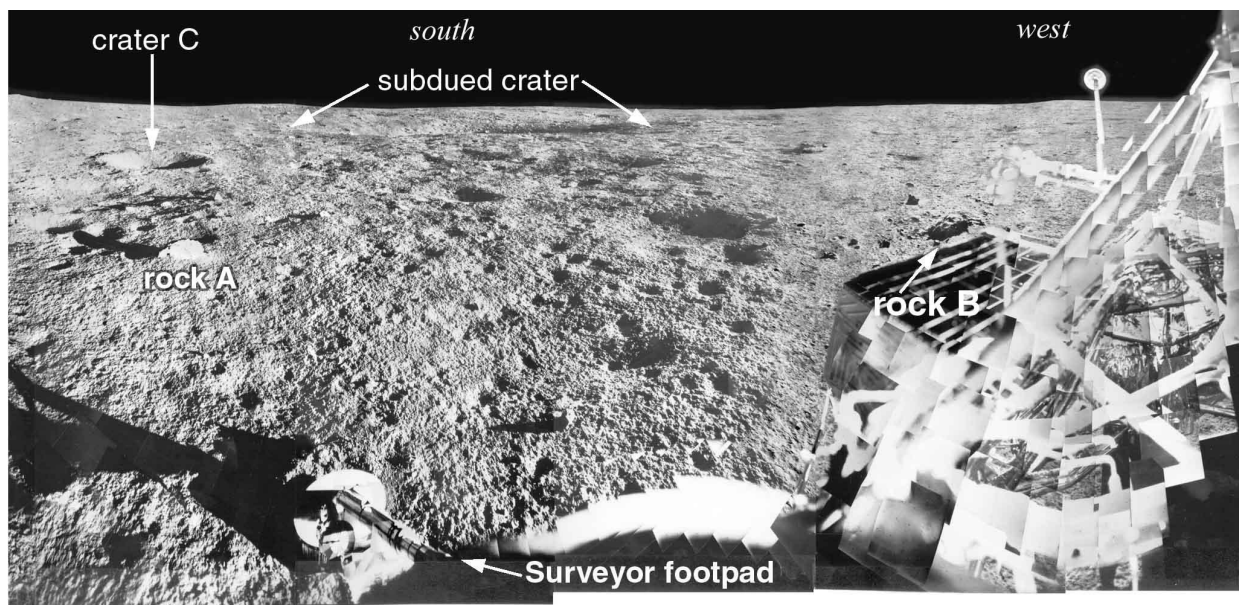


Figure 46 (both pages): Surveyor 1 images. A: full panorama (both pages) taken shortly before sunset. B and C: hills visible above the horizon. D: a fresh (blocky-rimmed) crater, seen just before sunset. E: a subdued crater south of the lander. D, E and some other craters are identified in Figure 45D. F: a block field, probably the rocky rim of a crater, as shown in Figure 45D. Several additional rocks are identified in Figure 47.

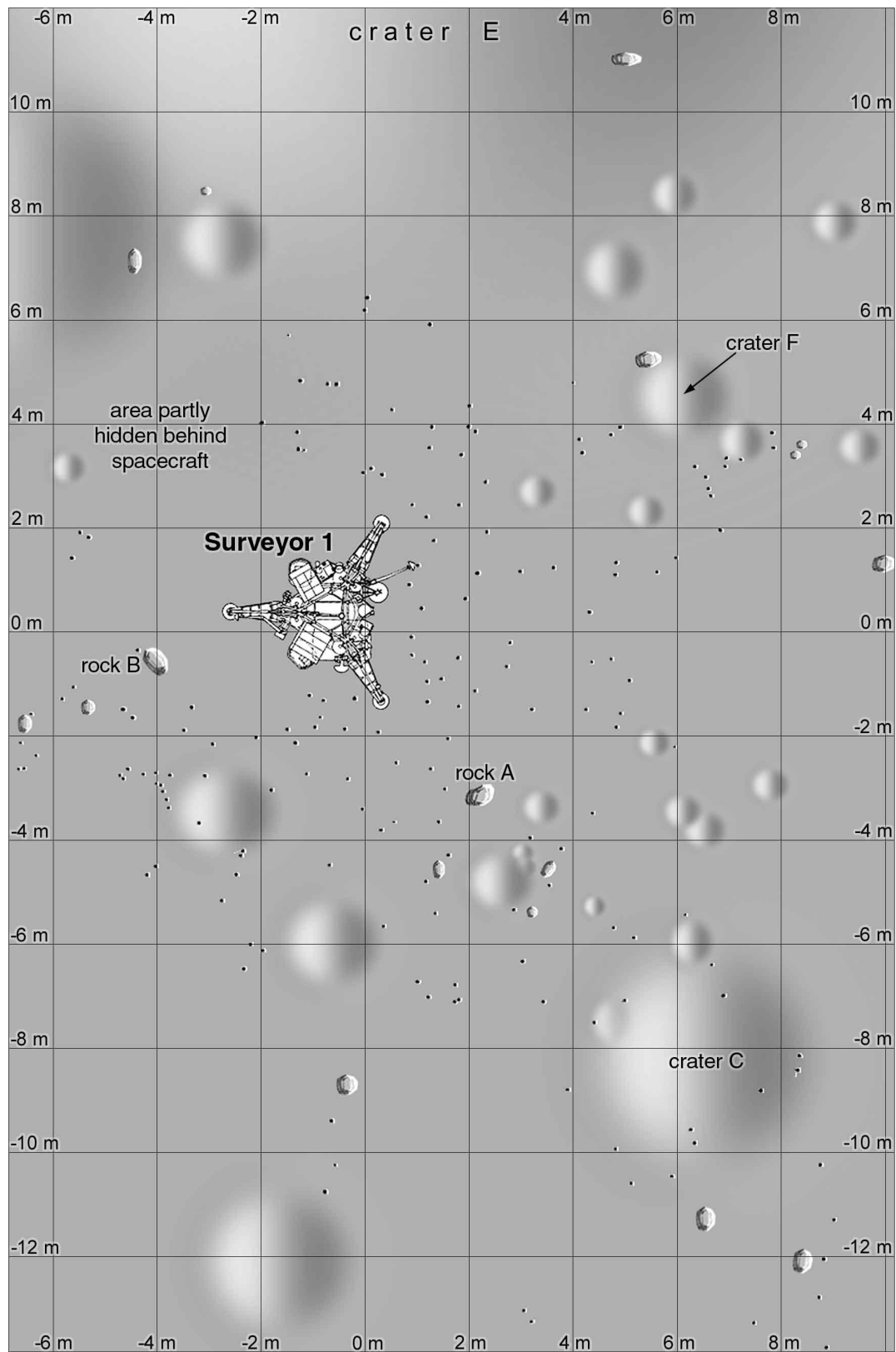
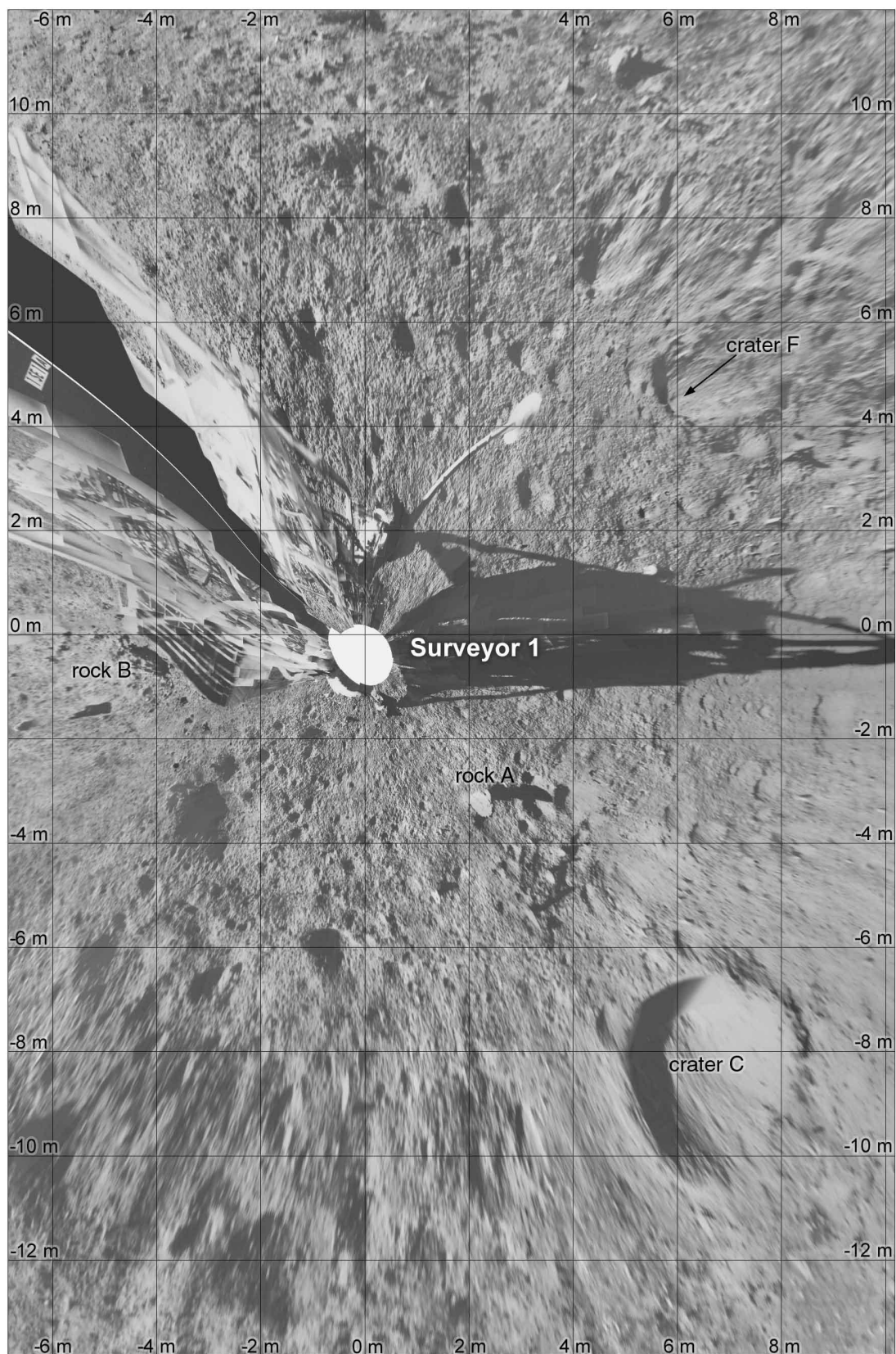


Figure 47 (both pages): The Surveyor 1 landing site, based on Fig. III-16 of JPL (1969). This page: Relief rendition by P. Stooke. Opposite: The afternoon panorama projected to match the JPL map.



Surveyor 1's camera obtained both wide angle and narrow angle panoramas of its surroundings under different lighting conditions, as well as colour composites taken through several filters and calibrated using a coloured target mounted on a footpad. One of the panoramas taken late in the lunar day, with the low afternoon Sun casting long shadows towards the east, is shown in Figure 46A. Details of this and other images are included in Figure 46, and a circular reprojection of the panorama showing more detail than Figure 47 is presented in Figure 48A.

The landscape was generally flat, but pocked with craters and small scattered rocks. The hills forming the rim of Flamsteed P (Figure 44A) protrude above the northern horizon (Figures 46B, 46C). A 50 m diameter fresh crater surrounded by small rocks (Figure 46D) is identified in Figures 45D and 48B. Older, subdued craters flanked the lander to the north (crater E) and south, about 40 and 60 m across respectively. The largest crater in Figure 45D, southeast of the lander, was 200 m wide and had many large blocks on its walls, but it was barely visible in the panorama except as a line of rocks just below the horizon. A prominent cluster of these rocks (Figure 46F) marks the rim of a small superposed crater (Figure 45D, 48B).

Surveyor 1's retro-rocket was dropped from an altitude of 14 km shortly before landing and fell near the landing site. There are no pre-landing images to help locate it, but by comparison with the Surveyor 3 and 6 sites where pre-landing images make the identity of post-landing features unambiguous, the retro-rocket impact is probably the dark spot noted in Figures 48B and 48C. It lies 350 m west-northwest of the lander, on the ejecta of a fresh 25 m impact crater, and an enlargement of LRO image M122495769L reveals it as a 2.5 m diameter crater with a small dark ejecta deposit (Stooke, 2016).

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- Whitaker, E. A., 1966. Surveyor 1 location. *Science*, v. 153, pp. 1550-1551.



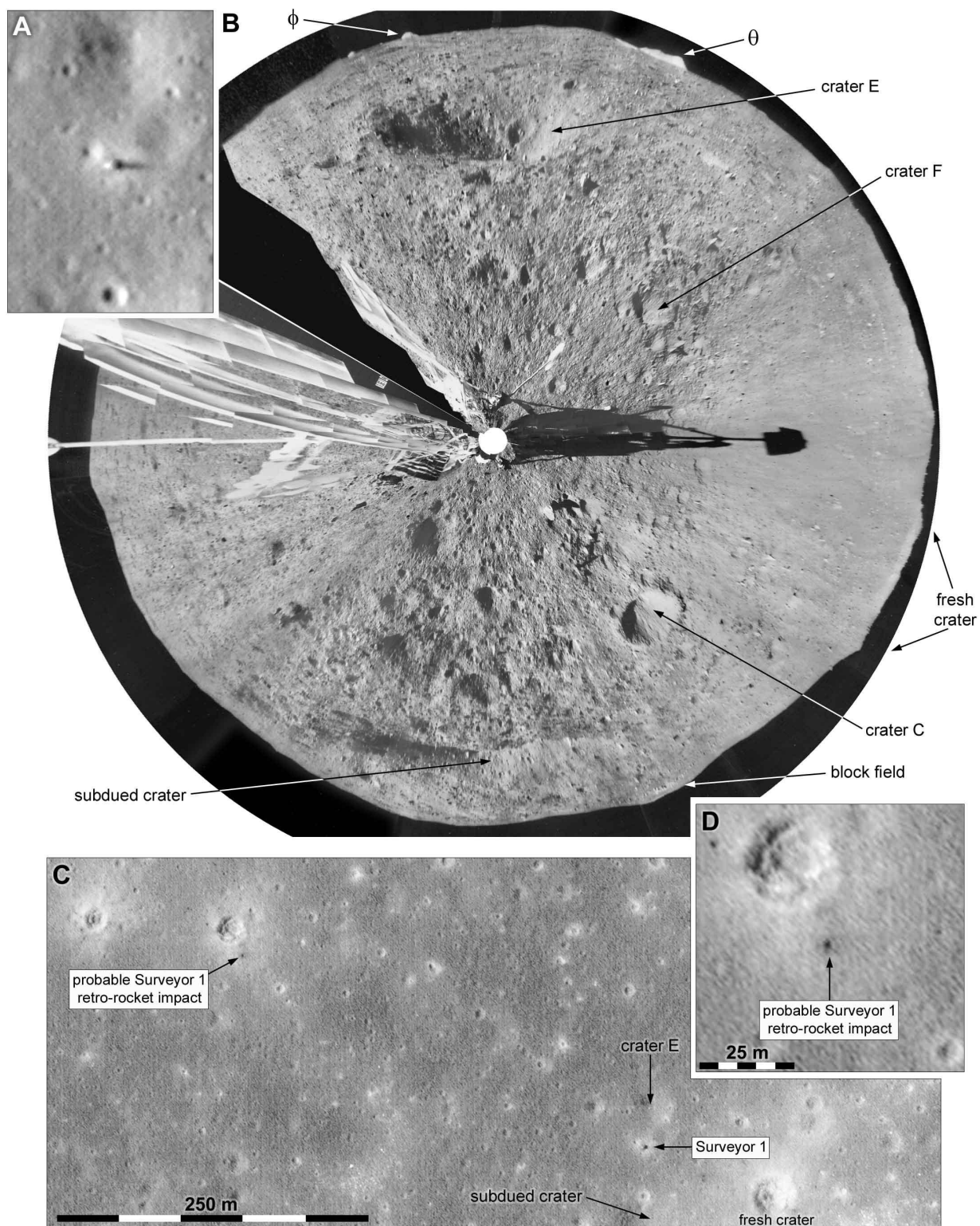


Figure 48: Surveyor 1 surroundings. A: composite of five LRO NAC images of Surveyor 1. B: reprojected panorama showing the vicinity of the lander. C, D: LRO image M122495769L showing the probable location of the retro-rocket impact.

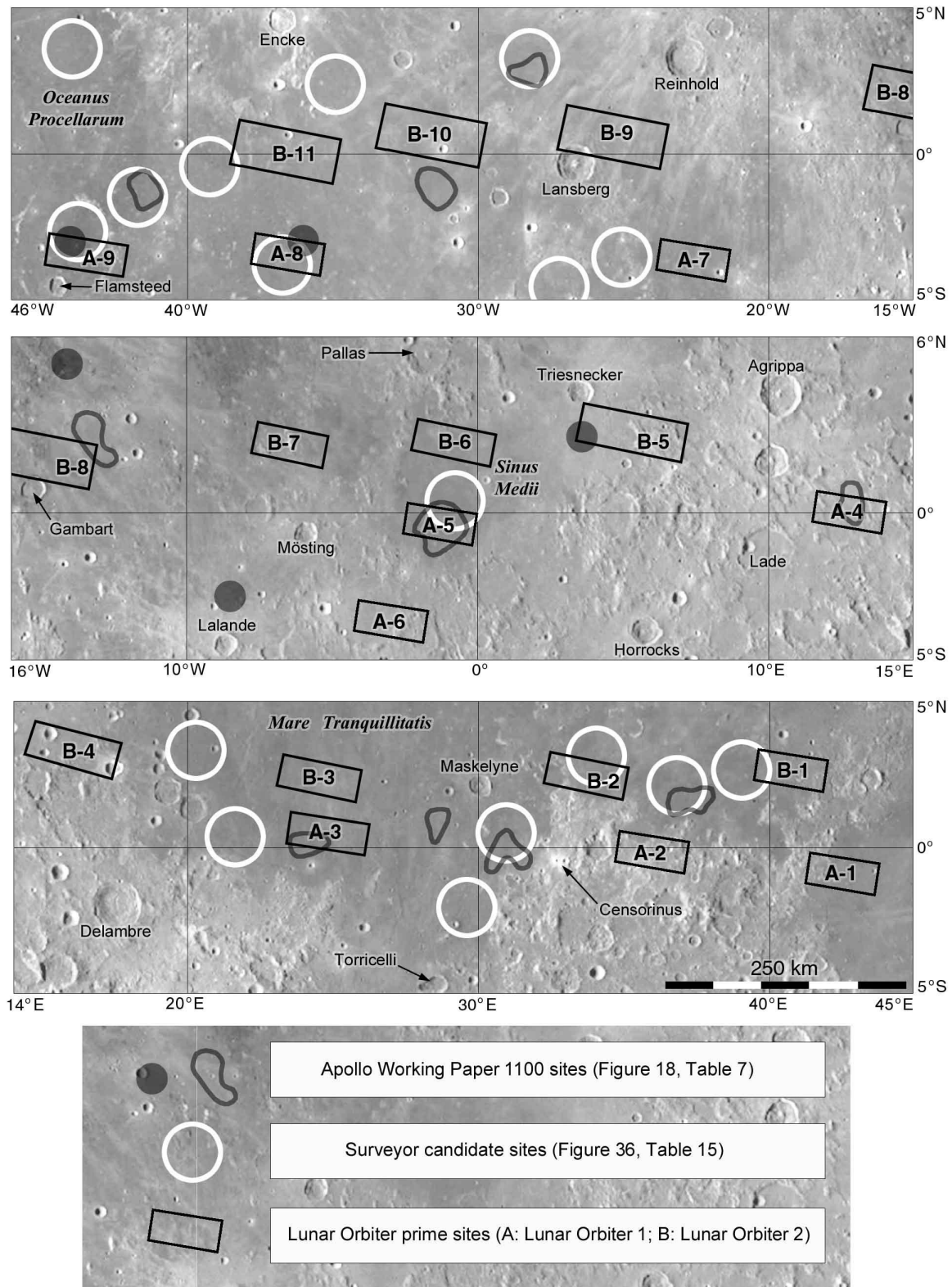


Figure 49: ASSB candidate sites considered in 1966. Base map: LROC wide angle mosaic. For scale, 1° of latitude or along the equator spans 30 km.

01 June 1966: Apollo Site Selection Board

With the launch of the first Lunar Orbiter mission immanent, site selection moved into the phase of targeting high resolution observations in order to assess and certify potential sites. Before launch the Orbiters were referred to as Mission A, B and so on. Areas chosen for photography were identified as prime sites, those of most interest to Apollo, and supplementary sites, of lesser interest to Apollo but with broader scientific or future planning value. The Lunar Orbiter spacecraft could not survey the entire Apollo zone at high resolution, so promising targets had to be selected in advance. For the first two orbiters, sites were chosen hurriedly using the limited information then available, guided especially by the assumption that mare surfaces with rays were rougher than areas between rays. This idea had already influenced Ranger and Luna landing site selection.

This meeting considered accessibility and launch dates for the prime sites for missions A and B (black rectangles in Figure 49, with site numbers taken from the ASSB minutes). Exact coordinates and site designations changed frequently in this period. Apollo Working Paper 1100 sites (Figure 18, Table 7), some of which correspond to the new set of prime Orbiter sites, are shown in grey in Figure 49. Candidate Surveyor sites which were also being considered for Apollo by the time of the next meeting (Figure 36, Table 15) are shown as white circles. The word site was used here to describe an area 50 to 100 km across in which targets might be located, not a specific target point.



1 July 1966: Explorer 33

This NASA spacecraft was intended to orbit the Moon in order to study interplanetary plasma, charged particles, magnetic fields and solar X-rays. The 212 kg spacecraft was a spin-stabilized eight-sided prism with four tilted solar panels, eight antennae and an orbit insertion rocket engine. It was launched from Cape Canaveral on a Delta booster at 16:04 UT on 1 July 1966. It failed to enter lunar orbit but did achieve its main mission objectives with data collection from widely varying elliptical orbits about Earth, out to and beyond lunar distances. Data collection continued until 21 September 1971.



10 August 1966: Lunar Orbiter 1

The Lunar Orbiter program was managed by NASA's Langley Research Center. The first spacecraft in the series was launched from Cape Kennedy Launch Complex 13 at 19:26 UT on 10 August 1966 on an Atlas-Agena D booster. Its goal was to photograph possible Surveyor and Apollo landing sites from orbit at resolutions sufficient to certify safe sites. The camera system is described by Elle *et al.*, 1967, and the mission by NASA (1967).

The Lunar Orbiter spacecraft body ('bus') was a truncated cone, 1.65 m high with 1.5 m base diameter. The equipment deck held the battery, a star tracker, flight control electronics and the camera system. Images were recorded on film, which was processed on board and the resulting negatives scanned and transmitted to Earth. Four solar panels extended from this deck with a 3.72 m total span, as well as a dish antenna on a 1.32 m boom and an omnidirectional antenna on a 2.08 m boom. The solar panels provided 375 W of power to operate the spacecraft and to charge the battery, which was used while the Orbiter was in shadow. Above this another deck held the orbit control engine and fuel tanks, sun sensors and micrometeoroid detectors. A heat shield protected the spacecraft from the rocket exhaust, the nozzle of the engine passing through the centre of the shield. Four nitrogen gas attitude control thrusters were mounted around the perimeter of the heat shield.

The launch vehicle placed the 386 kg spacecraft in its parking orbit, then the upper stage placed it on a 92.1 hour lunar trajectory at 20:04 UT. A midcourse correction was made at 20:00 UT on 11 August. A planned second correction was not needed. A temporary failure of the star tracker orientation system was worked around by navigating using the Moon as a reference. Another problem with overheating was solved by reorienting the spacecraft relative to the Sun to lower the temperature. An orbit insertion burn on 14 August placed Orbiter 1 in its initial orbit, 189.1 km by 186.8 km, inclined 12.2° to the equator and having a period of 217 minutes. This was the first successful U.S. lunar orbital mission. On 21 August the spacecraft lowered its perilune to 58 km and on 25 August to 40.5 km.

From 18 to 29 August, Lunar Orbiter I imaged nine candidate Apollo sites, including the Surveyor I site, as well as seven other potential Apollo sites, the east limb of the moon and 11 areas on the farside. Most of the important targets were imaged as intended. Lunar Orbiter I also took the first images of Earth from the vicinity of the Moon. A total of 207 pairs of medium resolution and high resolution frames were taken, 38 from the initial higher orbit, the rest from the final low orbit. Most of the high resolution images were badly smeared because an image motion compensation system failed (Wilhelms, 1993, Chapter 9), but otherwise the cameras and spacecraft performed well. Data transmission continued until 14 September. Radio tracking, used to study the lunar gravitational field, suggested the Moon had a slightly pear-shaped polar cross-section (Michael *et al.*, 1966). The spacecraft looked for micrometeorite impacts without success, and monitored radiation intensity (Hansen, 1970).

Figure 50 shows the areas photographed by Lunar Orbiter 1 in the equatorial region of the nearside. Candidate Apollo landing sites (Figure 49) were now designated prime sites (IP, using roman numerals to designate the spacecraft) and are shown with heavy outlines in Figure 50. Other imaging targets, called supplementary sites, were additional exposures made necessary by a requirement to move the film at regular intervals, and are shown in subdued tones. The targets were chosen to extend knowledge of lunar features and the farside. The Lunar Orbiter 1 supplementary sites east of Mare Fecunditatis would have helped identify navigation landmarks used to update the final orbit before landing.

The original version of the imaging plan had ten prime sites. Site A10 (top section of Figure 50) was dropped to allow more images of the Surveyor 1 site, and after Surveyor 1 landed Site A9 was moved and renamed first 9.1 and then 9.2 (here IP-9.2) in an attempt to image the landing site. Similarly site IP-8.1 was a modified target location.

Figure 51A shows the areas on the farside covered by Lunar Orbiter 1 images. These views, including very high resolution frames in the centre of each large medium-resolution frame, gave the first detailed look at the terrain seen indistinctly by Luna 3 and Zond 3 (Figures 14 and 61). Several images of the western limb of the far side showed the crescent Earth above the horizon.

After the end of the image transmissions the spacecraft was deliberately crashed onto the Moon to avoid interference with future flights. Impact occurred on the farside at about 6.7° N, 162° E on 29 October 1966 during the 577th orbit (Figure 51B). A contemporary analysis gave the nominal impact (target) point as 6.38° N, 163.70° E, and a prediction based on doppler tracking after the de-orbit burn as 6.8° N, 162.2° E. The final orbit analysis suggested that the actual impact point was 6.35° N, 160.71° E (Boeing Co., 1967). Analyses like these were necessarily made assuming a spherical Moon because the actual topography was unknown, and with a very oblique impact the prediction may be significantly in error. Lunar Orbiter 1 approached the surface from the west and struck a region of higher than average topography, suggesting an impact west of the predicted point.

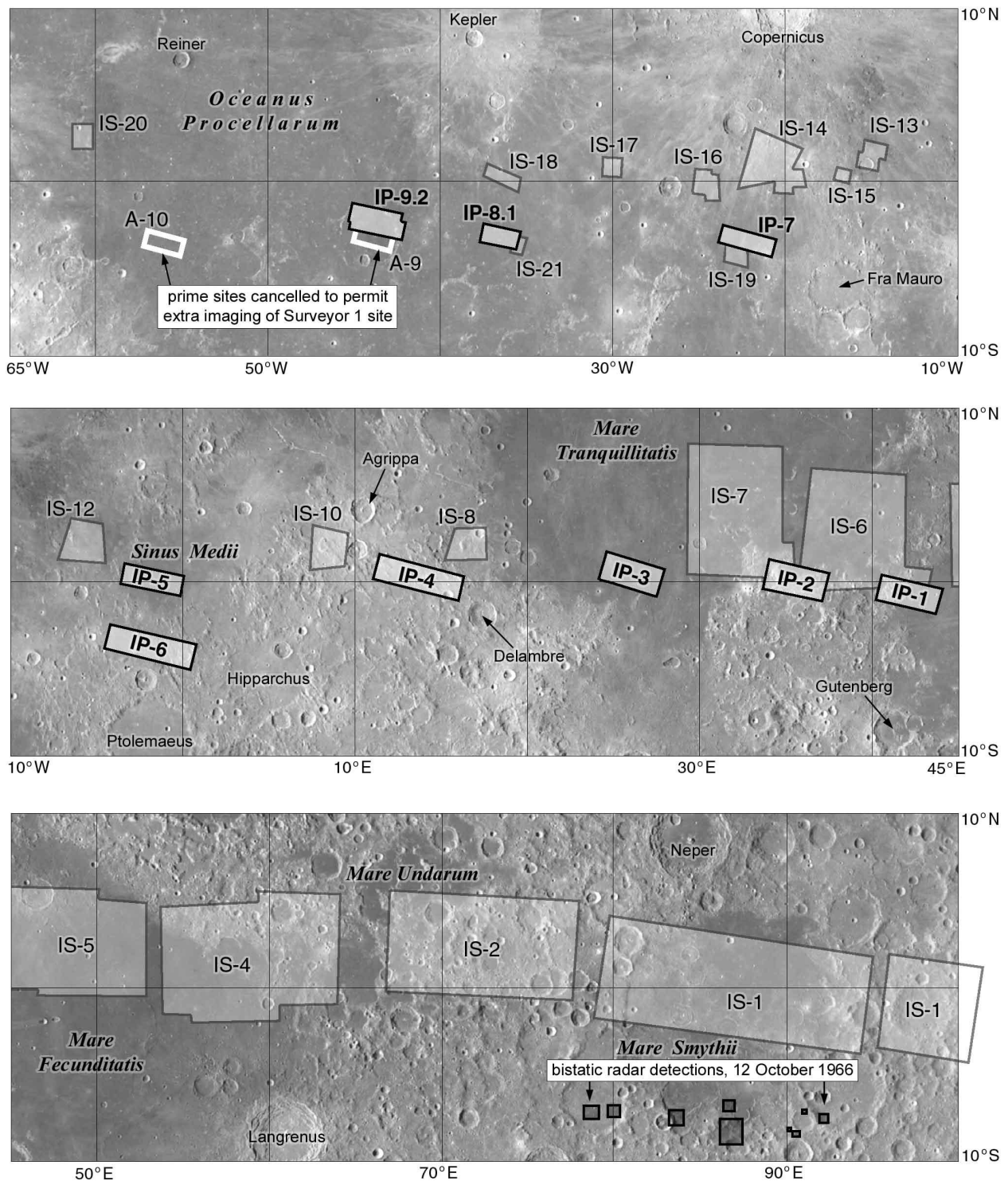


Figure 50. Lunar Orbiter 1 nearside image coverage. P indicates prime sites, S indicates supplementary sites, and the preceding I indicates Lunar Orbiter 1 (using the roman numeral). Base map: LROC wide angle mosaic. Nine areas detected by bistatic radar (bottom) were described by Tyler *et al.* (1967).

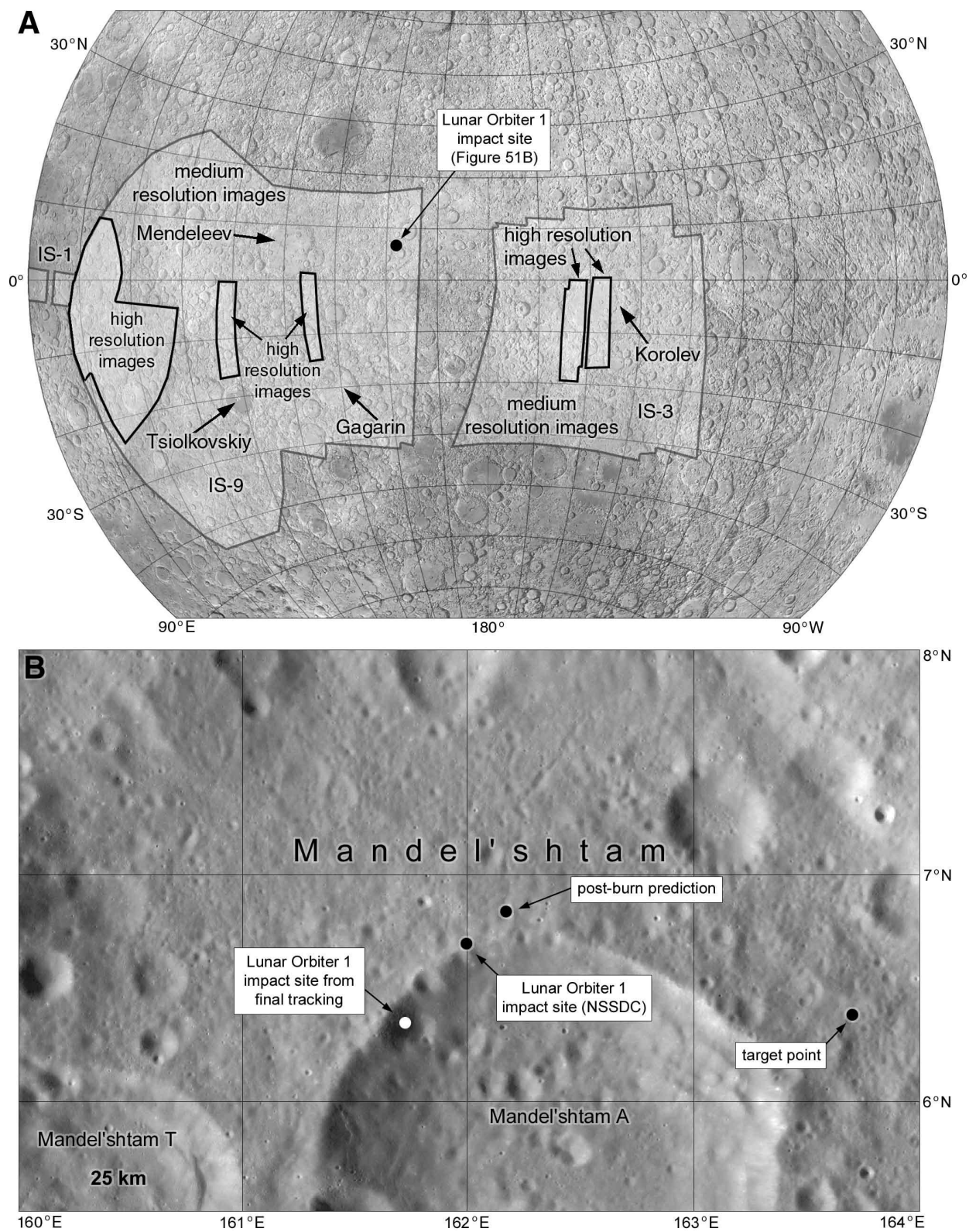


Figure 51. Lunar Orbiter 1 farside image coverage and impact site. A: Farside image coverage. The impact site is indicated. B: The impact site showing estimated impact locations on an LROC wide angle mosaic.

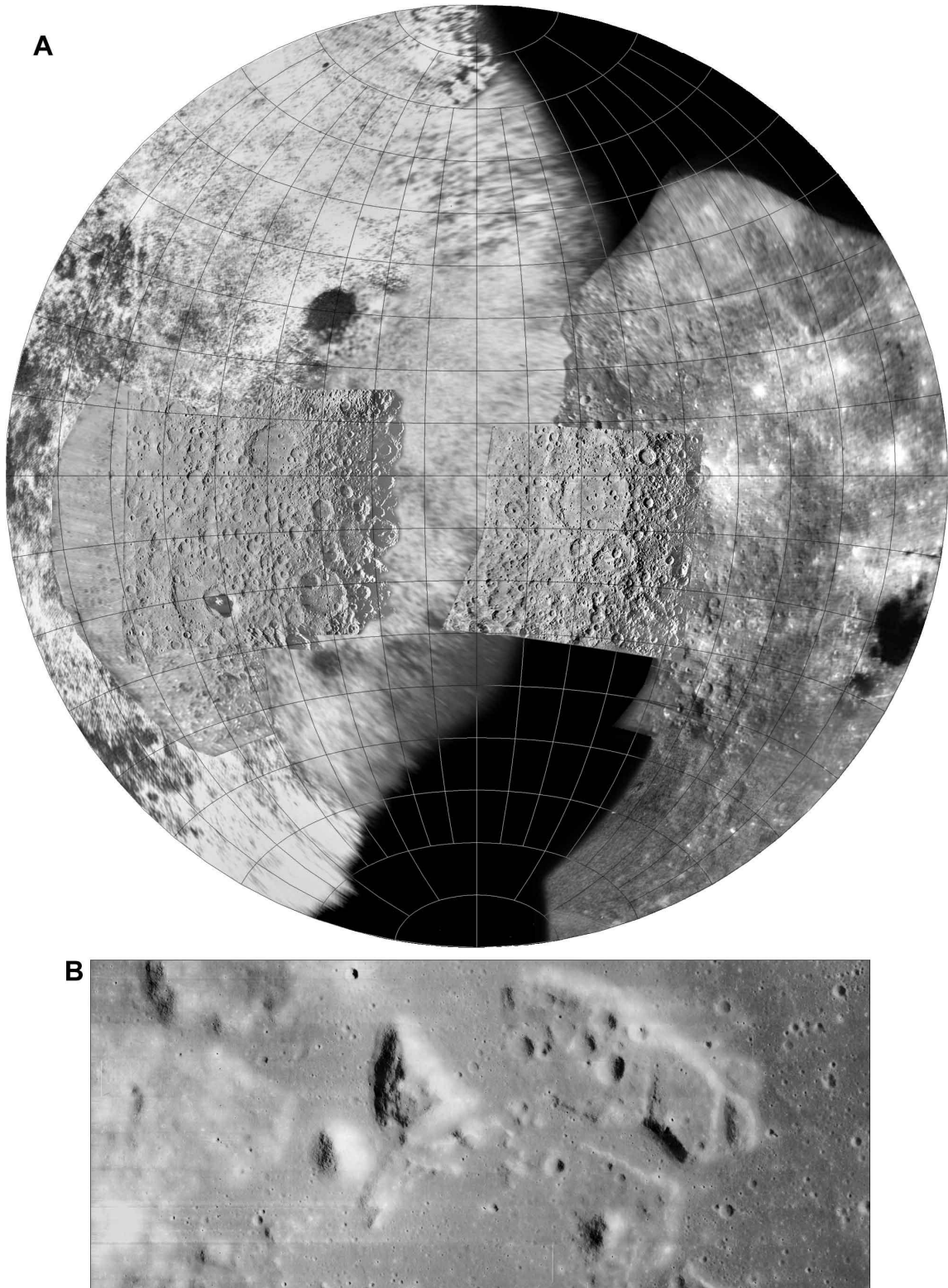


Figure 52. Lunar Orbiter 1 images. A: farside image coverage after the Lunar Orbiter 1 mission. This follows Figure 37C and the sequence is continued in Figure 58A. B: part of Lunar Orbiter 1 image LO1-060-M showing site IP-1 at 1° S, 42° E near the edge of Mare Fecunditatis.

Figure 52 shows the farside as it was known at the end of the Lunar Orbiter 1 mission. Coverage by Luna 3 and Zond 3 was now augmented by the first high resolution coverage, including the first detailed views of the spectacular dark-floored crater Tsiolkovskiy and the large impact basins Korolev, Gagarin and Mendelev. Figure 52B is part of the imaging coverage of potential Apollo site IP-1.

Lunar Orbiter 1 also conducted bistatic radar observations of the lunar surface (Tyler *et al.*, 1967), starting slightly later than the similar experiment by Luna 11. The spacecraft, moving towards the limb, transmitted radio signals which were reflected off the lunar surface and received on Earth. The spacecraft was above Mare Smythii and near its lowest altitude (40 km) on 12 October 1966. Nine features were detected and interpreted as more compacted or fortuitously tilted regions which enhanced the reflection of radar signals (Figure 50).

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Table 16. Spacecraft locations on the Moon, in this volume.

Spacecraft	Date of contact	Location	Event
Luna 2	13 September 1959	29° N, 0° E or 26.42° N, 2.08° E	Impact
- Upper stage	13 September 1959	c. 27° N, 70° E	Impact
Ranger 4	26 April 1962	15.5° S, 130.7° W	Impact
Ranger 6	2 February 1964	9.386° N, 21.481° E	Impact
Ranger 7	31 July 1964	10.63° S, 20.55° W	Impact
Ranger 8	20 February 1965	2.638° N, 24.787° E	Impact
Ranger 9	24 March 1965	12.828° S, 2.387° W	Impact
Luna 5	12 May 1965	1.6° S, 25.0° W	Impact
- Upper stage	12 May 1965	32° S, 8° W	Impact
Luna 7	7 October 1965	9.8° N, 47.8° W or 9° N, 51° W	Impact
Luna 8	6 December 1965	9.13° N, 63.30° W	Impact
Luna 9	3 February 1966	c. 8.0° N, 63.67° W	Landing
Surveyor 1	2 June 1966	2.474° S, 43.339° W	Landing
Lunar Orbiter 1	29 October 1966	7° N, 161° E	Impact